REPORT RESUMES

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VARIATIONS IN INSTRUCTIONAL MEDIA, PROCESSES, CONTENT AND APTITUDE VARIABLES IN RELATION TO EFFICIENCY OF COGNITIVE GOAL ATTAINMENT, VOLUME 1.

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A SERIES OF STUDIES WAS UNDERTAKEN, DIRECTED TOWARD EXPLORATIONS OF INTERRELATIONSHIPS AMONG MEDIA, PROCESSES (INSTRUCTIONAL PREREQUISITES), CONTENT AND APTITUDE VARIABLES, AND ACHIEVEMENTS. EMPHASIS THROUGHOUT WAS ON (1) THE COGNITIVE DOMAIN AND (2) PROBLEMS INVOLVED IN APPLICATION OF KNOWLEDGE TO A PRACTICAL TEACHING SITUATION. "THE TAXONOMY OF EDUCATIONAL OBJECTIVES" (BLOOM AND OTHERS) PROVIDED THE INTERPRETATION OF "ACHIEVEMENT" IN TERMS OF WHICH STUDIES WERE MADE OF THE STRUCTURE OF DEPENDENT AND INDEPENDENT VARIABLES. SPECIFICATIONS WERE PREPARED, AND INSTRUCTIONAL SEQUENCES BASED ON THESE SPECIFICATIONS WERE PREPARED IN THE AREAS OF (1) MATRIX ALGEBRA, (2) FORTRAN PROGRAMING, (3) SYMBOLIC LOGIC, AND (4) ANALYSIS OF VARIANCE. ALSO, BASED ON THESE SPECIFICATIONS, ACHIEVEMENT EXAMINATIONS WERE PREPARED. EMPIRICAL STUDIES OF THE MATERIALS DEVELOPED WERE CARRIED OUT IN AN ATTEMPT TO COLLECT EMPIRICAL DATA FOR FURTHER ANALYSIS. A MODEL OF THE SYSTEM OF MEDIA INSTRUCTION AND AN OPERATION OF THIS MODEL (A SIMULATION OF THE OPERATION OF THIS SYSTEM) WERE DISPLAYED IN THE REPORT. IT WAS POSSIBLE TO MAKE A SYSTEMS ANALYSIS OF A HYPOTHETICAL MEDIA INSTRUCTIONAL SYSTEM, TO DEVELOP A MODEL, AND TO GENERATE RESULTS TO CONFORM TO EMPIRICAL FINDINGS. IF THIS APPROACH CAN BE GENERALIZED TO SIMILAR CIRCUMSTANCES IN LATER STUDIES, IT WILL LAY SOME OF THE GROUNDWORK BRIDGING THE GAP BETWEEN RESEARCH AND PRACTICE IN THE MEDIA FIELD. TWO APPENDIXES TO THIS REPORT WERE ASSIGNED ACCESSION NUMBERS ED 003 240 AND ED 003 241. (HB)

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Volume I

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ABSTRACT

This report consists of a series of studies directed toward explorations of inter-relationships among media, processes (instructional prerequisites), content and aptitude variables, and achievement. Emphasis throughout has been placed on the cognitive domain, on problems involved in application of knowledge to a practical teaching situation.

The Taxonomy of Educational Objectives (Bloom, et al) provided the interpretation of "achievement" in terms of which studies were made of the structure of dependent and independent variables. Specifications based on the explorations in "II" were prepared, and in turn instructional sequences based on these specifications were prepared in the areas of matrix algebra, FORTRAN programming, symbolic logic, and analysis of variance. Also, based on these specifications, achievement examinations were prepared.

Empirical studies of the materials developed were carried out in an attempt to collect empirical data for further analysis.

A model of the system of media instruction which was studied, and an operation of this model (i.e., a simulation of the operation of this system) are displayed here. An algorithm for the exploration of trade-off functional relationships among the independent variables is given, as well as the results of an application of this algorithm to empirical data here generated.

It was possible to make a systems analysis of a hypothetical media instructional system, to develop a model, and to generate results to conform to empirical findings. If this approach can be generalized to similar circumstances, it will lay some of the groundwork for future studies bridging the gap between research and practice in the media field.

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PREFACE

This report consists of a series of studies, rather than a single study. All of the studies were directed toward the exploration of interrelationships among media, process (instructional prerequisites), content and aptitude variables in relation to achievement as defined by the Bloom and others' Taxonomy -- knowledge, comprehension, and application levels. The intent was to attempt a systems analysis of media instruction.

Materials for the basic studies are indicated in the various sections of the appendices:

Appendix I deals with problems of meaning and reference in Bloom's Taxonomy.

Appendix II and associated deliberations led to use of rating sheets such as shown in II, called "Scale for Appraising a Model"-- a subjective rating device; but a means of obtaining judgments where they were needed and not available.

Appendix 3 is a brief discussion of the model which guided the selection of studies. At the beginning media alone could not be classified except in terms of hardware--motion picture, slides, audio tape, teaching machine, etc. -- an unsatisfactory approach. Putting media into a matrix form, as suggested by Gagne Varieties of Learning, in part solves the problem. Media are now classifiable in terms of how well they satisfy the prerequisites for learning at the Taxonomy's levels of knowledge, comprehension, and application. The same sort of medium, motion picture for example, may have different ratings depending upon how well it satisfies prerequisite conditions. Motion pictures do in fact differ widely in their capability for teaching.

Similarly the Taxonomy alone and content alone give no particular grip on the problem, but put together into a matrix they seem to fit both logically and empirically.

Appendix IV presents an alternate to isolobes for exploring trade-off relationships among interacting variables. Isolobes were derived from pharmacology. Similar concepts are found in the economist's indifference curves, or the engineer's transfer functions. The purpose is to discover how many units of A and B, and in what combinations, are possessed by individuals at the same level of achievement. Fitting the curves is a tedious process that requires among other things quadratic interpolation. When there are many hundreds to be fitted the project becomes monumental and the returns do not justify the cost. The proposed alternative procedure was designed to yield an analog that would be useful for practical purposes, and would be both inexpensive and rapid. Trade-off results appear to be specific to the population and cognitive dimensions studied. It is hazardous to extrapolate too far.

Appendix V illustrates the materials used for the matrix instructional units.

Appendix VI illustrates the FORTRAN instructional materials.

Appendix VII illustrates the symbolic logic instruction materials. All three of these blocks of instructional units attempted to simulate the tutor situation basically contrasting print plus workbook, with programmed lecture plus workbook. Other variables such as level of ability; inductive vs. deductive development of topics were also included in the design. Treatments were equated in terms of scoring on the media x processes matrix and on the subject matter x taxonomy matrix. No significant differences were found, suggesting that when using equalized materials the particular hardware was of no special significance.

From the standpoint of modeling the media instructional situation, this introduces a useful simplification. Intercorrelation matrices and factor loadings appear to support this view.

Statistics instructional materials developed for the project are indicated in Appendix IX. These were put into a linear programmed form. The stems of the items are much longer than they could be for less mature subjects. Data on this study were not comparable to the other three studies and are not reported.

Appendix X presents a brief discussion of a general purpose procedure oriented computer programming language (P. O. L.) that was being developed as an alternative to SIMSCRIPT. It was designed to accomplish the kind of simulation needed in this sort of study more directly than SIMSCRIPT.

Results are summarized in each section. Outcomes include: The suggestion that applied research in media is more involved than appears on the surface. Analysis of variance or correlating methods are not enough. Education has not yet worked out the methodology for translating research into practice. Older areas like engineering have had more experience in this sort of activity. Whether the same methods are useful in instruction remains to be seen. Initial results suggests that there are ideas worth pursuing here, but eventually education will have to work out its own strategies.

Products include the instructional materials which have been useful in helping succeeding classes of students overcome certain deficiencies in quantitative area. The materials have provided a catalyst for others on our faculty to develop similar materials.

Results raise more questions than they answer, but the questions are those that have not been raised very often before -- namely, how does one deal with a conglomeration of variables rather than a single one in the practical situation.

The methodology used was an attempt to translate into media research some of the strategies that have been used in business, engineering, and government to good advantage.

VARIATIONS IN INSTRUCTIONAL MEDIA, PROCESSES, CONTENT, AND APTITUDE VARIABLES IN RELATION TO EFFICIENCY OF COGNITIVE GOAL ATTAINMENT

Background:

The study was directed toward a systems analysis of patterns of audio-visual media, processes, content, and aptitude variables in relation to their efficiency for goal attainment within the cognitive domain. In the proposal it was indicated that possible relationships to either the affective or psychomotor domain of goal attainment would not be explored. Experience with the study suggests that a more nearly complete and more realistic description of reality could be obtained by inclusion of the affective domain in particular.

Sample:

In the study it was indicated that mature subjects, college students and possibly advanced high school students, would be used as subjects. Fleishman and Hempel[1] demonstrated that aptitude pattern structure varied with the maturity level of students. The choice of mature subjects as the sample was reinforced by Bloom's[2] volume on Stability and Change in Human Characteristics. After examining the vast literature available Bloom concludes:

1. The relation between parallel measurements over time is a function of the levels of development represented at the different times.

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[1] Fleishman, E. A. and Hempel, W. E. "Changes in Factor Structure of a Complex Psychomotor Test as a Function of Practice". Psychometrika 1954, 19, 239-252.

Fleishman, E. A. and Hempel, W. E. "The Relation Between Abilities and Improvement with Practice in a Visual Discrimination Reaction Time Task." Journal of Experimental Psychology 1955, 49, 301-312

[2] Bloom, Benjamin S. Stability and Change in Human Characteristics N.Y., Wiley, 1964.

2. Change measurements are unrelated to initial but they are highly related to relevant environmental conditions in which the individuals lived during the change period.
3. Variations in the environment have greatest quantitative effect on a characteristic at its most rapid period of change and least effect on the characteristic during the least rapid period of change.

Hence it was argued that mature subjects would show less variability and greater stability than others. It was recognized that the proposed study had enough sources of contamination of variances and relationships without deliberately introducing additional ones due to rapid development.

The subject matter we proposed to investigate--matrix algebra, computer programming, and statistics--were more appropriate for the mature student. The major source of subjects then was the experimental teacher education program, INSITE (Instructional Systems in Teacher Education) and the students in the regular teacher training curriculum for elementary and secondary school teachers. Additional subjects were obtained from the graduate student population, and the summer institutes of the National Science Foundation, in the case of a computer programming study. Details on the sample are given in the discussion of the studies.

The Taxonomy:

The dependent variable was the cognitive domain as defined by Bloom[3] and others. Specifically the Taxonomy might be sketched in brief outline form as follows:

---

[3] Bloom, B. E. (ed) Taxonomy of Educational Objectives. Handbook I: Cognitive Domain. N. Y.: David McKay and Co., 1956.

TABLE I: Bloom's Taxonomy of Educational Objectives

- 1.00 Knowledge
    - 1.10 Knowledge of Specifics
        - 1.11 Knowledge of terminology
        - 1.12 Knowledge of specific facts
    - 1.20 Knowledge of ways and means of dealing with specifics
        - 1.21 Knowledge of conventions
        - 1.22 Knowledge of trends and sequences
        - 1.23 Knowledge of classifications and categories
        - 1.24 Knowledge of criteria
        - 1.25 Knowledge of methodology
    - 1.30 Knowledge of Universals and Abstractions in a field
        - 1.31 Knowledge of principles and generalizations
        - 1.32 Knowledge of theories and structures
- 2.00 Comprehension
    - 2.10 Translation
    - 2.20 Interpretation
    - 2.30 Extrapolation
- 3.00 Application
- 4.00 Analysis
    - 4.10 Analysis of elements
    - 4.20 Analysis of relationships
    - 4.30 Analysis of organizational principles
- 5.00 Synthesis
    - 5.10 Production of a unique communication
    - 5.20 Production of a plan, or proposed set of operations
    - 5.30 Derivation of a set of abstract relations
- 6.00 Evaluation
    - 6.10 Judgments in terms of internal evidence
    - 6.20 Judgments in terms of external criteria

Robert L. Wilhoyte[4] of our staff addressed himself to the task of explicating and evaluating the meaning of Handbook I. Wilhoyte discusses the "theoretical and meta-theoretical" and the "philosophical" aspects. Four principles are applied in his examination:

1. Correspondence with empirical data.
2. Logical development and internal consistency.
3. External consistency with respect to psychological research.
4. Descriptiveness and completeness.

At the time of writing the only empirical study directly related to the taxonomy was that of Furst at Chicago. Wilhoyte indicates that "Regardless of the level of abstraction, it must be remembered that the Taxonomy is empirically grounded and, therefore, can be falsified by instances which are counter to the defined structure. Hence to assess the success or failure of the Taxonomy on the criterion of principle one is an on-going matter which will require additional research and careful analysis."

Some of the empirical testing we proposed to do by factor analysis of items on the achievement tests, to note if the factors describing homogeneous sub-scores correspond to the factors postulated, and built into the tests originally. Ayres at the University of Alberta has been doing similar work, and indicates that his results are to be reported at the American Educational Research Association meetings in Chicago, February 1966. Essentially Ayres reports a factor analysis of a 40 item, 4-option multiple choice test administered to 297 students immediately following completion of a Grade 10 science program on Gas Laws. Students were taught by a common programed instructional unit. An a priori classification of items was made to provide criteria for rotation of the factors extracted and to check on the adequacy of the a priori classification. Phi and tetrachoric interitem correlations were computed for the items. Two easy items were dropped because they interfered with the adequacy of the factorization. The principal components method was used to extract 16 factors. The taxonomy is supported in small part by what little empirical evidence exists

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[4] See Appendix 1, R. L. Wilhoyte Problems of Meaning and Reference in Bloom's Taxonomy: Cognitive Domain Unpublished PhD. thesis, Au 1965.

In terms of the logical development and internal consistency principle, the Taxonomy should satisfy three rules regulating a logical division.

1. There must be only one defining characteristic at each step.
2. The division must be exhaustive.
3. The successive steps of the division (if there exist more than one) must proceed by gradual stages.

It is clear that the Taxonomy does not meet these requirements. [illegible] practice, however, the usefulness of a set of criteria is merely in setting standards. It is expected that standards will not be completely met. Therefore the rules should not be interpreted as inviolate laws, but as a set of guidelines, which if followed, could yield a product that can be effectively used in ordering experience. In part the Taxonomy satisfied this condition.

Principle 3 must be regarded as an operational rule also, which serves as a continuous criterion for relating the hypothetico-theoretical taxonomy to the emerging matrix of psychological and educational research. When inconsistencies are exposed, reconciliation through reconstruction must be made. The alternative is a loss of efficiency with reference to explanation and communication.

With reference to the fourth principle--descriptiveness and completeness--we can say that although descriptions are empirically based, a class of described events is not coextensive with a class of actual events which have occurred, but rather with a class of possible events whose actual occurrence is contingent upon given circumstances. For every instance of a possible educational objective, there is a verbal description that corresponds to it. Descriptions, then, are the raw unsorted data which are classified.

In terms of Wilhoyte's analysis the Taxonomy is far from complete. Unfortunately it is still probably the most useful categorization that we have. In the long run the value of the Taxonomy will be determined by how well it stands up empirically. Logical analysis will be restructured increasingly to fit valid empirical data. In other words, although a philosopher and logician is not happy with the Taxonomy, no one seems to have developed a more useful scheme. We used it because there was nothing better to be had at the time.

Initial analyses of the dependent variable in each of the studies to be reported proceeded by means of a matrix. For example, consider computer programming as the subject matter content. A logical or other arrangement of content alone was deemed incomplete. Therefore, a bivariate chart form was used. Along the top, as column headings were placed the rubrics of Bloom's Taxonomy. Along the left margin was placed the topical heading of the subject matter to be covered. Thus the rows refer to subject matter content, and columns refer to levels of the Taxonomy. Their intersection indicates the particular subject matter that contributes to a specific goal in the taxonomy. Furst showed that there was some agreement between items within a subject matter classification, and there was less agreement between the taxonomic categories. Our own results tend to confirm Furst's. In other words, there seems to be little evidence that comprehension is as homogeneous in structure as a topic with the content field. In any scheme used for describing the operation of the independent and dependent variables in the systems analysis there must be provision for a wide variety of specifics.

Table II.

MATRIX FOR INSTRUCTIONAL BLUEPRINT

Taxonomy

	1.00 Knowledge						2.00 Comprehension			3.00 Application	4.00 Analysis		
	1.10		1.20										
	1.11	1.12	1.21	1.22	1.23	1.24	2.10	2.20	2.30		4.10	4.20	4.30
1. Basic Concepts input-output instruction modification													
2. Intermediate system instruction format branching													

Note: The rest of the Taxonomy, items 5 and 6, could not be used on the content we programed for the present study.

Not all cells could be filled by an item on the test, or the unit of instruction. The easiest to fill part of the Taxonomy was the first, as would be predicted in a hierarchical system of this sort. We have commented at length on the Taxonomy because it is a focal part of the present study. The validity and dependability of its categories are directly reflected in the dependability of the information collected thereby.

Aptitude:

The next topic of concern is the categorization of the aptitude domain. The proposal suggests that aptitude variables will be defined by using Guilford's "dimensions of intellect" scheme, at least for a start. In his most recent presentation[5] Guilford describes it as the structure-of-intellect (SI) model. It still consists of five operation categories (cognition, memory, divergent production, convergent production, evaluation), six product categories (units, classes, relations, systems, transformations, implications), and four content categories (figural, symbolic, semantic and behavioral). When efforts were first made about 1955 to organize the intellectual abilities identified by factor analysis, 37 abilities were recognized. In 1958,[6] there were 43 such abilities within the model. From then on, the model served as a source as to the kinds of abilities to look for. At the time of writing, 80 abilities were believed to be identified and were placed within the model. Of the 120 cells, 75 are actually occupied.[7]

In evaluating the model we found a number of difficulties. The large number of factors seemed to be overwhelming, and this feeling was compounded when one looked at the rate of emerging new factors.

---

[5] "Intelligence: 1965 Model" American Psychologist 1966, 21, 20-26

[6] "Three Faces of Intellect" American Psychologist 1959, 14, 469-479

[7] The discrepancy between 75 and 80 lies in 3 cells found to contain 2 abilities each and 1 contains 3. Duplications arise from distinctions among parallel visual, auditory, and kinesthetic cognitive and memory abilities. Guilford adds "More such duplications are to be expected when appropriate investigations are made."

Guilford and associates have published a few including: *Christensen-Guilford Fluency Tests,* 1 form, measuring (a) word fluency, (b) ideational fluency, (c) associational fluency; *Decorations* measuring "divergent production of figural implications" or "ability to add meaningful details"; *Match Problems* "divergent production of figural transformations" or "originality in dealing with concrete visual material"; *Pertinent Questions*--conceptual foresight; *Possible Jobs*--"divergent production of semantic implications" or "ability to suggest alternative deductions." Additional Guilford tests appear in the *Kit of Reference Tests for Cognitive Factors, 1963 Revision*--*Simile Interpretations*, *Word Arrangement*, *Consequences*, *Ship Destination*; *Object Synthesis*, *Picture Gestalt*, *Logical Reasoning*, *Apparatus Test*, *Seeing Problems*, *Seeing Deficiencies*, *Utility Test*, *Alternate Uses*, *Object Naming*. This is a long way from 75 tests, but even then it complicates the problem unduly.

One can begin to agree with Humphries,[8] who is disturbed by the SI model because of (1) the proliferation of factors as more and more experimental test batteries are intercorrelated and factored Guilford recognizes many more factors than Thurstone had tests. (2) The tendency to think of factors as basic or primary no matter how specific, narrow or artifical the test behavior that factor is based on. Merely because a number of scores have been intercorrelated, the correlations factored, and some interpretable factors obtained is no adequate basis for concluding that these are primary factors which should be used henceforth in practice and for further research.

---

[8] "The Organization of Human Abilities" *American Psychologist* 1962, 17, 475-483

These two difficulties become even more pressing with the wide availability of computers. Except for the decision as to the number of factors to rotate, factor analyses can now be ground out "without having the basic data seen by the human eye or touched by the human hand."

Humphries agrees that one should use factor analysis as an aid to hypothesis generation, but not neglect other aspects of hypothesis formation, especially as when we factor we need a model of the nature of individual differences. This model must be provided by the investigator.

Humphries starts with the now plausible assumption that test behavior can be made endlessly more specific,and factors can be endlessly fractionated. When two test differ only slightly so that by definition they are not parallel forms, but are almost as highly correlated as parallel forms, we have by present practice the definition of the ultimate primary factor. To construct systematically nonparallel tests that differ only slightly, each must be highly homogeneous. This would lead to a large number of tests scalable in the original Guttman meaning. For each there would be a near parallel form. Such factors would define factors endlessly, many more than Guilford is suggesting, but these would not be what Humphries would recognize as primary. Most of the Guilford studies are directed toward analytic study of human intellect rather than predictive validity of the instruments.

While considering the Structure of Intellect model we were impressed by the sparcity of tests for it, so we considered for a while the Kit of Reference Tests for Cognitive Factors handled by E. T. S. These tests cover the following factors: CF--flexibility of closure, CS--speed closure, FA--associational fluency, FE--expressional fluency, FI--ideational fluency, I--induction, LE--length estimation, MA--associative (rote) memory, MK--mechanical knowledge, MS--memory span, N--number facility, O--originality, P--perceptual speed, R--general reasoning, RE--semantic redefinition; RS--syllogistic reasoning, S--spatial orientation, SEP--sensitivity to problems, SS--spatial scanning, V--verbal comprehension, VZ--visualization, XA--figural adaptive flexibility, XS--semantic spontaneous flexibility. Each of these has anywhere from 2-5 tests, or taking each test separately there are 74 tests. There are 74 tests in the group, and the testing time would occupy several days. Obviously we could not hope to implement the testing program in this case. Hence as a result we were inclined to agree more with Humphries and favor the hierarchical model of Thomson and other British psychologists. This decision is not due solely to the unwieldy character of the SI model. It is in part conditioned by the fact that reports of published studies showed that factors held no particular advantages for predictive purposes. Since they were derived primarily for investigating the structure of intelligence, little attention was paid to predictive criteria. The Thomson model specifies different levels or hierarchies of functioning ranging from the most general "g", through broad group factors to narrow group factors and specifics.

The conclusion to favor a more operational and less structural model can be independently verified by means of analysis of judgments on the "Scale for Appraising a Model" given in Appendix 2. Scores for the Guilford model appear to be slightly lower than for the hierarchical.

In any case the criterion here was predictive ability. It was argued that a general measure such as the School and College Ability Tests, the Otis Quick Scoring Mental Abilities Test, The Vocabulary Analogies Test, which is similar to the Miller Analogies, would provide satisfactory estimates of "g". Information relative to group factors-- verbal, numerical, education--was provided by Doppelt Mathematical Reasoning Test, Christensen-Guilford Fluency Tests, and Brown-Carlsen Listening Comprehension Test. Information relative to group factors--spatial, practical, mechanical, physical--comes from the Ship Destination Test, Guilford-Zimmerman Aptitude Survey, part 5, Spatial Orientation. No mechanical knowledge test was given because it did not seem pertinent. Specific tests include the pretests of the various subject content fields-- e.g. separate matrices pretest--knowledge, comprehension, and application levels; computer programming--knowledge, comprehension, and application,-- and likewise for statistics and symbolic logic. Other specific aptitude tests include Watson-Glaser Critical Thinking Appraisal, Allport-Vernon-Lindzey Study of Values, High School Record, Personal background data, and first semester grades in the University.

Instructional Process and Audio-Visual Variables:

Instructional process and audio-visual variables are treated in this section. The point of view that motivated the present study has been well expressed by Gagne[10].

> "Although many people, including me, have tried for years to account for actual instances of learning in terms of a small number of principles, I am currently convinced that it cannot be done. To the person who is interested in knowing what principles of learning apply to education, my reply is: The question must be asked and answered with consideration of what kind of capability is being learned. The answer is different depending on the particular class of performance change that is the focus of interest. There are no 'general' rules of learning known at the present time that can be used as guides in designing for instruction.
>
> There are, however, a number of useful generalizations that can be made about several distinguishable classes of performance change (learning) of which I think there are at least eight. These principles are discussed in this book as the conditions of learning."

Identification of the varieties of learning relative to conditions that produce them has some definite implications for instruction.

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[10] The Conditions of Learning N.Y.: Holt, Rinehart and Winston, 1965

Features of the instructional process should be determined by the requirement of helping students learn effectively. These features must be specified and planned before the student is placed in the learning situation. There must be planning in terms of the student's capabilities; Where does the student start? Where is he going? What are some of the prerequisites for learning? What will the student be able to learn?

A learner starting out cannot do certain essential things for himself. Getting the student started; determining and arranging the content and direction of learning require planning and resources. Outcomes need to be assessed to advise the student what he has been able to accomplish, to let him know where he is and help him go ahead efficiently.

Instruction thus means arranging the conditions of learning; considering the level of capability developed by the student, requirements of the next stage of learning, and the specific content for the present and next stage of learning.

For the present study instruction was predesigned rather than extemporaneous by a teacher. This was necessary in order to control and collect data relevant to the process.

Choice of media for instruction is basic to effective instruction. Media may be oral and printed communications; it may be hardware ranging from a line drawing to mixed media split-screen computer-controlled television and motion pictures. Effectiveness is not determined by the hardware characteristics. Required conditions for learning are differentially satisfied by differing media. Media can be valuable resources for learning or extraneous hindrance depending on the relevance to the purposes at hand. Some media may merely talk, others like the digital computer may approach a tutor session type of instruction.

Varieties of learning have been classified by Gagne* as

1. Signal learning
2. Stimulus-response learning
3. Chaining
4. Verbal association
5. Multiple discrimination
6. Concept learning
7. Principle learning
8. Problem solving

These are arranged in hierarchical order. Problem solving, type 8, requires all the preceding 7 as prerequisites. Concepts, type 6, require the preceding 5 as prerequisites, and is itself in turn a prerequisite for type 7, principle learning.

Decisions that affect planning for learning include:

1. Defining the nature of change sought; the objectives of learning. Several writers have emphasized the importance of defining the objectives of learning in terms of observable performance.

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*The Conditions of Learning, Holt, Rinehart, Winston, 1965.

Mager[11] indicates that just to say a student is expected to know something, or to understand something, or to appreciate something is not satisfactory for planning instruction. The idea that a student should understand matrix algebra is a good general statement, but it is just stage setting for defining objectives. Verbs that describe overt action provide more objectivity: state (summarize in your own words), derive (make a series of sequential logically consistent statements based upon certain identified assumptions), identify (choose or point to). Operational definitions should make it possible for one person to identify the same human performance as another, and may include:

a) A verb describing observable action

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[11] Mager, R. F. Preparing Objectives for Programmed Instruction. San Francisco: Fearson, 1964

Lindvall, C. M. (ed.) Defining Educational Objectives. Pittsburgh: U. of Pittsburgh Press, 1964

Tyler, R. W. "Achievement Testing and Curriculum Construction", pp. 391-47, in Williamson, E. G. (ed) Trends in Student Personnel Work Minneapolis: U. Of Minnesota Press, 1949

French, W. Behavioral Goals of General Education in High School. N. Y.: Russell Sage Foundation, 1957

Kearney, N. C. Elementary School Objectives. N. Y.: Russell Sage Foundation, 1953

Bloom, B. (ed) Taxonomy of Educational Objectives. Handbook 1: Cognitive Domain N. Y.: John McKay, 1956

b) A description of the content or class of stimuli to which the subject is expected to respond.

c) An indication of the object used for action by the performer--state a theorem, prove a lemma.

d) A description of the class of correct responses.

2. Determining the learning sequence; After the change to be sought has been specified one can start to analyze it into subsets of topics, each a specifiable learning act, that must be considered as a prerequisite attainment of the objective. Each subset can be further analyzed until one arrives at prerequisites that the student already possesses. Each subset set is derived from its predecessor by the question: What must the student know and be able to do in order to learn this? A description of what students must know defines the subset of objectives.

3. Decisions about motivation; Motivation is probably the first task of the teacher. Learning takes place by activity of and within the learner. Something must initiate and direct this activity.

4. Maintaining motivation for achievement by keeping students informed of their achievement of objectives. Tests or exercises are useful at frequent intervals for giving the student feedback about his performance. Without such feedback learning becomes a blind oscillation process ("hunting") within error.

5. Choosing conditions for learning. These may be predesigned or extemporaneous. Predesign appears to be useful; it permits

choosing the proper learning conditions deliberately rather than on the spur of the moment; quality does not suffer from variations in teacher skills. Predesign makes possible pretesting (if a set of learning conditionsdoes not fit this will show up in trying it out on students.. Predesign permits revision, reduces need for teacher to use precious time for extemporaneous design, and makes it possible to direct attention toward managing instruction, motivating, generalizing, and assessing.

In considering media resources for learning consider first the function they can serve for learning efficiently. Begin with a rev iew of the instructional situation, then consider the purposes that particular devices can fulfill as well as purposes they cannot The modes of instruction can then be described--lecture, recitation, tutoring, and laboratory. Each mode requires different arrangements of media.

The environment of the learner has many features that are important for learning. These features are congruent with the instructional situation. Functions that must be performed by an effective instructional situation include: (1) Presenting the material to be learned. Materials may be presented in many ways--print, pictures, oral communication... --How it is presented depends on the type of learning desired. If a chain of responses is being learned, an external cue must be provided for each link, even though these are dropped later. If multiple discrimination, the items to be discriminated must appear so that correct connections can be identified from incorrect ones. If concepts, a wide variety of the class represented must be available. If problem solving, the problem situation must be appropriately represented. (2) Direct attention and learner activitities. Oral and printed directions serve to direct attention of most people who are past the primary years--"Complete the following statement", "how is a matrix multiplied by another?" Directions are not learning: they are actions that must be taken by the learner to create the proper condition for learning. (3) Provide a model for terminal performance. Informing the learner about the general nature of the performance to be acquired is important to learning. Most often oral and printed communication are used. (4) Furnishing external guidance. Cues in the instructional situation establish a proper sequence of connections and increase distinctiveness of stimuli. When no longer needed, these extraneous cues may be "vanished". Cues may be verbal, aural (as in the case of foreign language sounds), visual (showing a picture or drawing a diagram of a sequence). (5) Directing thinking. In problem solving the sequence of recalled material may be directed by instruction. Such guidance may reduce the number of irrelevant strategies. Instructions here usually take the form of oral or printed "suggestions" or "hints". (6) Providing for transfer. Transfer may be facilitated in a number of ways; usually the procedure is that of discussion, which usually begins with a question, or problem, whose answer requires problem-solving behavior. Motion pictures may be used effectively to "put the students into a situation". A demonstration in science may be given with words, without words, with printed materials, or it may be shown by motion pictures. Effectiveness is not determined by the modality used but depends upon the extent that students can be brought into the situation. (7) Appraising learning. Level and extent of mastery of specific objectives is usually assessed by asking the student questions. These may be in any of several modalities and at various levels of subtlety--oral, printed, or in almost any audio-visual form. Questions are useful to the extent they are pertinent, accurately reflect the objective, and produce student activity. (8) Providing feedback. Responses of students to questions must be followed by information indicating correctness. Sometimes this information is easy to communicate as the solution of a simple mathematics problem. Sometimes it may be difficult to communicate as in the appraisal of a student theme.

These eight ways that external conditions act on the learner, combined with his own prerequisite capabilities for learning bring about the desired change in his performance. There are many ways to develop these conditions, and many varieties and combinations of objects, devices, and media may be used. The important point is not the hardware, but the utility and relevance of the means to the kind of learning at hand. The characteristics of various instructional media in performing the eight functions need to be considered in making a choice.

Media of instruction. Media of instruction may be defined as the components in the learning environment that stimulate or provide inputs to the learner. The teacher is, and is likely to remain, the major source of input. There are, however, devices ranging from printed page to split screen television that can provide inputs for the learner. These devices can only perform effectively if their contents are designed by people for the purpose of learning, and in learning it is well to be aware of all sources of student input.

Older media--teacher, printed or written material, books, chalk boards, natural specimens, and pictures--have long been a part of the instructional situation. Newer media--motion pictures, television, teaching machines--have attempted to combine input characteristics of books with other instructional functions. The kind of learning being attempted has fundamental significance in the choice of instructional media. The following table, adapted from Gagne, summarizes the functioning of various media on the eight functions of a teaching situation.

Table III

Instructional Functions of Various Media

	Function	Oral Communication	Printed Media	Still Pictures	Silent Motion Pictures	Sound Motion Pictures	Teaching Machines
1.	Presenting Stimulus	Some	Some	Y	Y	Y	Y
2.	Directing attention and learning activity	Yes	Y	N	Some	Y	Y
3.	Providing a model of expected performance	Yes	Y	Some	Some	Y	Y
4.	Furnishing prompts and cues.	Yes	Y	Some	Some	Y	Y
5.	Directing thinking	Yes	Y	N	Some	Y	Y
6.	Providing for transfer	Y	Some	Some	Some	Some	Some
7.	Assessment	Y	Y	N	Some	Y	Y
8.	Providing feedback	Y	Y	N	Some	Y	Y
	Score	15	14	5	9	15	15

Note: Scores were assigned by giving "Yes" a weight of 2, "Some" a weight of 1, and "No" a weight of zero.

These scores should not be interpreted too literally. They are intended to indicate potential or capability of the medium for carrying out the function. Actually each device or medium has to be assessed on its own actual performance of the function. This could be done judgmentally by asking a group of teachers and/or pupils to assign weights describing the adequacy of function performance; or by asking "experts" of various denominations and sorts to render their judgment. Assessment could be done empirically by collecting empirical data (by tests and observations) on typical subjects as to how well the function is performed. Assessment could also be done logically by observing extent to which logical connections exist between the medium application and the principles of instruction. (Judgmental and logical ratings are distinguished here mainly by the extent to which they are based on specific referents. The judgment can be an expression of the feeling or impression of the person. The logical requires specific reasons that form logical connections between the medium's strategies and materials and the objectives of the instruction.)

Systems Analysis of Instruction

The present study was directed toward developing a systems analysis for audio-visual instruction. Previous sections dealt with preliminary matters--exploration of the sample, the taxonomy for categorizing content, the classification of aptitude structure, and a discussion of the nature of processes and media used in instruction. Scales for assessing these matters were indicated. In this section we shall explore system analysis in general and how it is being used in the present study.

A system is a set of objects united by some form of interdependence. Each object in a system has certain properties which may be used to define it. Each object influences other objects and is in turn influenced by them. In system analysis the search is for the pertinent interactions among the parts.

This approach appears to be the opposite of the conventional research procedure of "cutting the problem down to size". It appears to enlarge the problem to include not only the units, but also their interactions. Actually the difference is not as great as might appear on the surface. System analysis still requires conventional procedures to gather data for its own unique feature--that of model building. A system and its operation are formally represented as a model.[12] The model may be physical, mathematical, or symbolic. The latter two types of model may be operated on a computer. Operating the model is usually described as simulation.[13]

Systems analysis thus refers to the construction of models and procedures to describe functioning of the variables involved in the model. Sometimes it may be possible to optimize, but often we must be content with "satisficing". Two sets of variables ordinarily may be identified--those that can be manipulated or controlled, and those which are not controlled but which affect performance. Interrelationships among these variables are our focus of interest.

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[12] For a good discussion of models see Freudenthal, Hans (ed) The Concept and the Role of the Model in Mathematics and Natural and Social Sciences. Colloquium, Utrecht Holland, N. Y.: Gordon and Bresch, 1961

[13] Fattu, N. A. "An Introduction to Simulation" Fourth Phi Delta Kappa Symposium on Educational Research, Bloomington, Ind. 1964

Models are employed to permit prediction of performance of existing systems, with or without modifications, in systems being designed. In this respect they serve several functions: (1) By operating the model one may make specific predictions about the outcome of the system without actually using a real system. Thus the model may be considered in terms of design objectives to observe whether or not intended outcomes appear to be achievable. (2) Determination of a "best" model. A number of different models are constructed and the performance of each is measured. The "best" design is chosen after comparison of the different dependent variables which measure the performance characteristics of the system.

In the context of education, design is analogous to the method used to accomplish instruction. In this study method includes as components instructional media, process, content and aptitude variables, rules for operating the model the way in which each component acts and interacts to produce changes in the dependent variables of cognitive goal attainment. In considering the components the focus is with functions and not with physical features. It would not help a jet aircraft, or model, fly better if we were to glue feathers on it.

A model once constructed can be used to determine values of the controlled variables that appear to produce the best performance of the system for specified values of the uncontrolled variables.

From the model of education once constructed one might derive solutions to problems of instructional effectiveness in at least two ways:

1. Conduct experiments, or simulation, on the model. Sometimes a solution to the problem can be determined without simulation; deductively[14] by analysis, rather than inductively. The model is effective, . . and only if, it is a good representation of reality.

2. Derive solutions to a problem and use them in a real situation. Various solutions may be compared to determine which gives the "best" solution.

Instructional system performance is evaluated in terms of student learning in relation to the categories of the cognitive domain -- knowledge, comprehension, application, analysis, and synthesis. Evaluation could not be readily measured in the present context. With the advent of programed instruction it has become possible to collect data on student performance in relation to the variables of instruction --media, processes, content, and aptitude. In fact programed instruction made possible studies such as those undertaken here. Perhaps the rationale may be explained by reviewing the general model and then indicating how it was implemented for further study.

The general sketch,without details of the Instructional Model of our present study,is given in Figure I.

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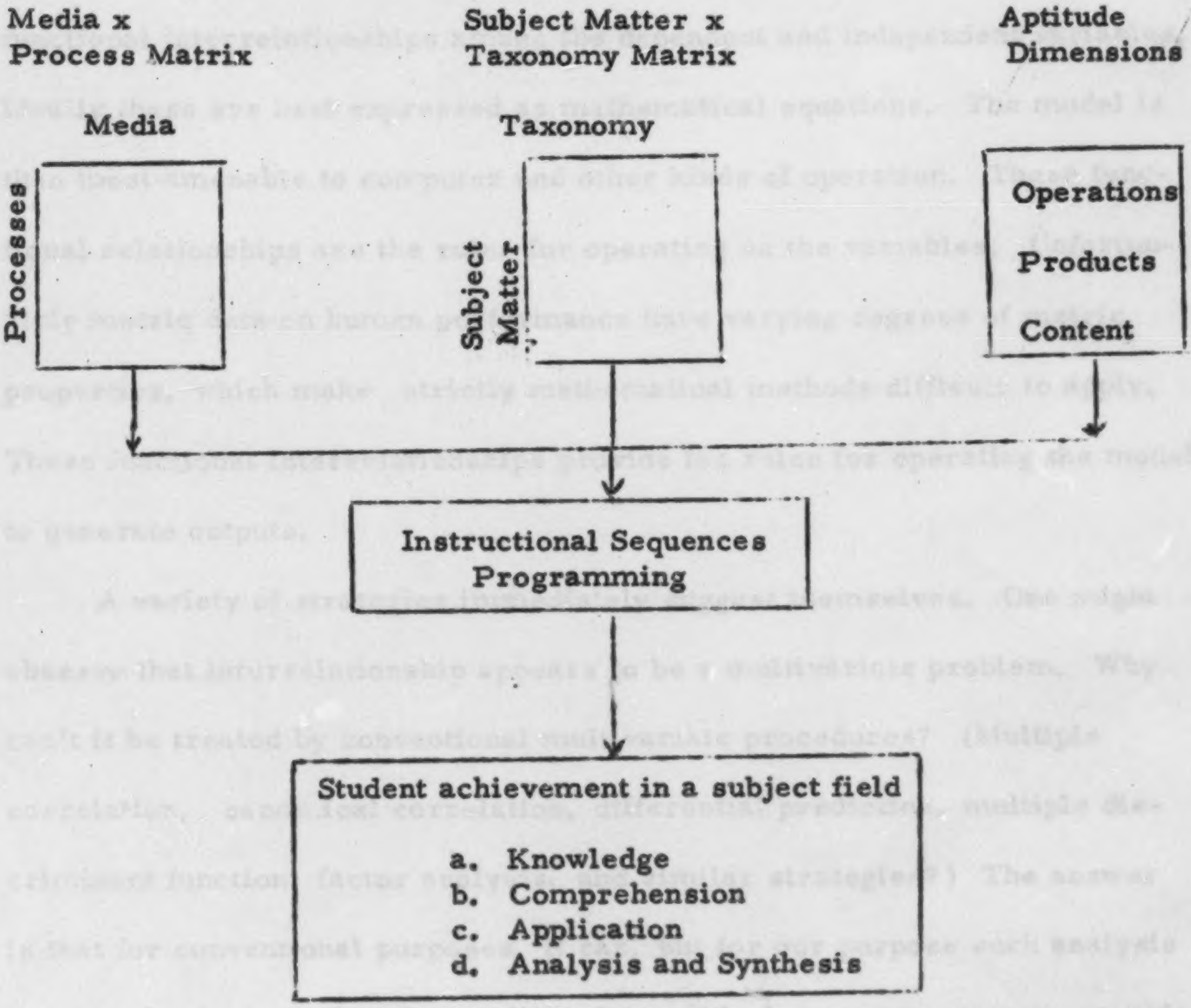
[14] Tocher, K. D. "The role of models in operations research." Journal of the Royal Statistical Society (A) 124:121-42, Part 2, 1961, tells how he and a group of technicians spent several months designing a model to solve a problem in World War II. One night the building burned down destroying everything. In his despair he sat down and worked out the solution analytically in a few hours.

Figure I: An Instructional System Model


Media x
Process Matrix
Subject Matter x
Taxonomy Matrix
Aptitude
Dimensions
Media
Processes
Taxonomy
Subject Matter
Operations
Products
Content
Instructional Sequences
Programming
Student achievement in a subject field
a. Knowledge
b. Comprehension
c. Application
d. Analysis and Synthesis

To implement the model it is necessary to begin, more or less, in the customary way of research, and

1. Collect data on each of the significant variables that it is possible to do so , and
2. Analyze and summarize these data.

Details of these steps are presented in the various studies of instruction in matrix algebra, computer programming, symbolic logic and statistics that follow. In any the similuation it is necessary first to construct and then to operate the model. Identification of the variables as we have done so far is only the barest beginning toward construction of the model. It is necessary to have data that indicate within what limits the variables appear to operate in order to begin constructing the model. It is next essential to find the functional interrelationships among the dependent and independent variables. Ideally these are best expressed as mathematical equations. The model is then most amenable to computer and other kinds of operation. These functional relationships are the rules for operating on the variables. Unfortunately metric data on human performance have varying degrees of metric properties, which make strictly mathematical methods difficult to apply. These functional interrelationships provide the rules for operating the model to generate outputs.

A variety of strategies immediately suggest themselves. One might observe that interrelationship appears to be a multivariate problem. Why can't it be treated by conventional multivariate procedures? (Multiple correlation, canonical correlation, differential prediction, multiple discriminant function, factor analysis, and similar strategies?) The answer is that for conventional purposes, it can, but for our purpose such analysis is just a beginning. Regular multivariate methods are necessary to provide a first approximation to the rules. Most multivariate procedures assume a linear relationship. In this domain linearity does not necessarily obtain. A good deal of the information is thereby masked. Of course, it is possible to fit curves of various kinds that summarize the relationship more completely, and this is what was done on one of the studies. Curve fitting was later discarded because of the sheer magnitude of the task both in deriving the relationships and later in making provision for their use to operate the model. The method of isolobes is described in appendix 3. To have carried it out completely would have required many thousands of curves to be fitted, and then summarized by the computer program. It turned out to be easier

and conceptually more satisfying to go back to the original data in each run. To be sure, the isolobes had some advantage. They permitted pay off relationships to be exhibited graphically. Thus one could literally "see" how much of one variable could be exchanged for another without sacrificing achievement. Tables of results were all two-dimensional. Thus, for a given dimension, one axis represented say, a dimension of aptitude (as indicated by a test score), the other dimension represented a dimension, say, of media-processes. All scores were expressed as STEN scores, e.g. on a scale of 1-10. This was punched on the cards as 0 to 9. On each table contours representing equal achievement (isolobes) levels were plotted representing the 90% achievement level, the 75% and the 60%. Graphically this may be represented as follows:

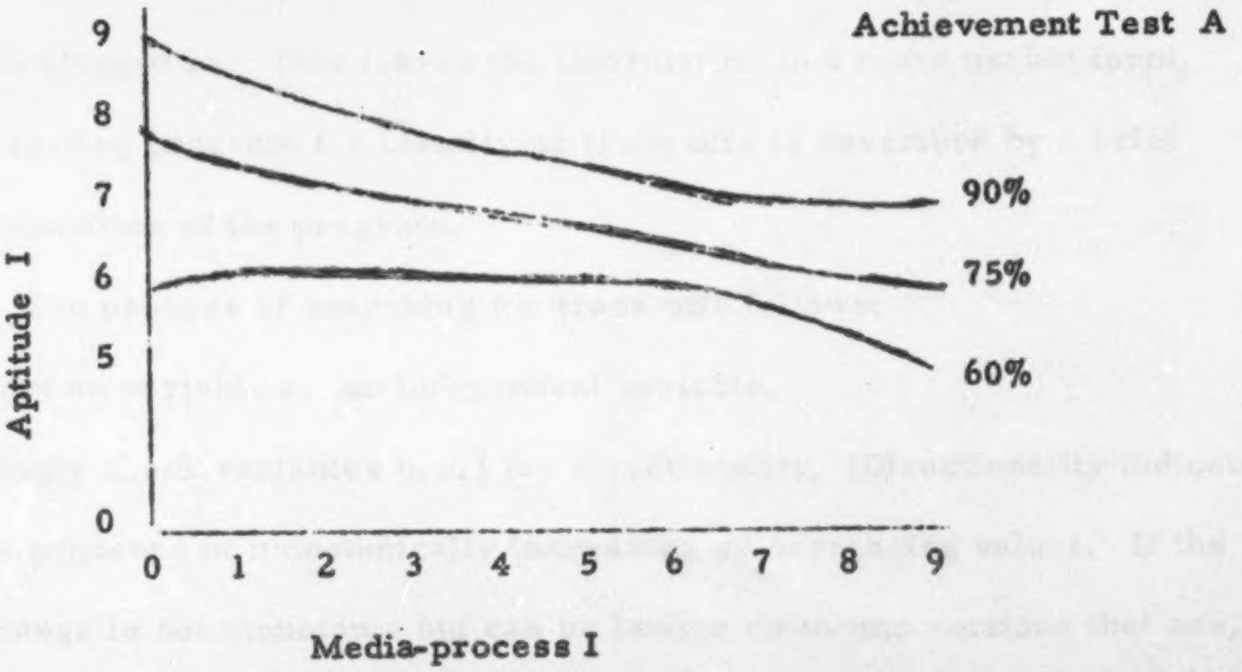


Figure II An Isolobe Diagram

The vertical dimension portrays aptitude, and the horizontal, media-process, The contour lines represent combinations of aptitude I and media-process variable I that had attained scores on achievement test A of 90%, 75% and 60% respectively. These curves were plotted by using quadratic interpolation methods -- a tedious process when there are many to be plotted. The 90% curve may be read as follows: A person with an aptitude STEN level of 9 and

and a media-process level of 1 earned an achievement score of 90%. Another person with an aptitude level STEN score of 7 and a media-process I STEN level of 9 earned a similar grade. Thus the latter was able to "trade-off" three STEN units of aptitude I against 8 STEN units of media-process I. This process eventually permits a description of the trade off relationship between pairs of variables and an achievement dimension. The hyperspace generated taxes the imagination, but is not beyond computer capabilities. However, programming takes some doing. In order to simplify matters, a more tractable procedure ', that described in appendix 4,was developed. This procedure is essentially a versatile program controlled sorter using magnetic tape or magnetic disk storage of STEN scores. To summarize the results of sortings a BIMED, or other appropriate statistical program, can be plugged in. This leaves the information in a more usable form, This sorting program for identifying trade offs is described by a brief documentation of the program.

The process of searching for trade offs follows:

1. Sort on variable a; an independent variable.
2. Singly check variables b...j for directionality. (Directionality indicates a sequence of monotonically increasing or decreasing values. If the range is not monotonic but can be broken down into sections that are, do so. Label + if an increasing directionality. In the case of a sequence that has been "broken down" into monotonic subsets, label the directionality and the range over which it holds.) Hold only uni-directional subsections. (Must be at least one-half the column length to be held at this point.)
3. Note variables with irregularities (Only held subsections count here.)

4. Note all uni directional columns individually and plus reduce* all combinations.

5. Establish hypothetical step size -- gross step size or approximations toward step size, ...

6. Obtain print outs of step size on relevant columns (subsections included)

7. Repeat sort on columns identified as irregular in step 2.

All of this must take into account what in the payoff columns is wanted. This program runs on each combination of payoff column values wanted.

Sample print out:

```
    FOR DESIRED VALUE G (*), H (*), I (*), TRADE OFFS ARE POSSIBLE
IN THE FOLLOWING RANGES OF THE FOLLOWING VARIABLES
VARIABLE              RANGE                  STEP SIZE

    A, C              A(5-9), C (8-3)        A (3), B(minus 1.86)
```

This procedure provides a rapid systematic way to locate relevant variables (those that can be traded off) and their distribution. Whatever summary statistics or calculations can be appended after the sorting process has identified useful variables.

Other strategies that might be used in exploring these payoff functions would be: (a) indifference maps and iso-product curves from economics; and (b) transfer functions from heat conduction studies in physics.

<u>Summary:</u> To explore the model relating variations in instructional media, processes, content, and aptitude variables with reference to variations in cognitive goal attainment, the following sequence of activities was used:

1. Identify the variables.
2. Find the dimensions, and the range within a dimension, that the variables operate. Construct a tentative model.

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*Iverson, K. E <u>A Programming Language</u>, N. Y.: Wiley, 1962, pp.16ff

3. Find the functional interrelationships among the dependent and independent variables. Try to express these as mathematical equation since they are then most amenable to computer treatment. These functional relationships provide the rules for operating the model. Include these rules in the model.
4. Prepare a computer program that summarizes the variables of the model, their range of scores, and the rules connecting them. Debug.
5. Operate the model by plugging in scores of a group you desire to study.
6. Compare results of computer run with results from a real situation.

Remember that when the computer run is on the group that was used for deriving the rules, the fit between simulated and real data is likely to be a maximum.

Study of Learning Topics From Matrix Algebra -I

The purpose of this study was to use programed topics in matrix algebra to explore the relationships among media, processes, content and aptitude variables in relation to achievement variables.

The theory of matrices was chosen because: 1) it is important in mathematics and has numerous applications in every branch of science, including the social sciences. Many of the computations made on electronic computers are based on matrix theory. Many problems in statistics are expressed in terms of matrices. Transition matrices are used in the study of Markov chains. In multiple correlation it is necessary to solve a system of normal equations for multiple regression coefficients. This is equivalent to finding the inverse of the coefficient matrix. In economics we find the examples in the input-output matrix and the game-theoretical payoff. Matrice are basic to factor analysis in psychology in which is many a problem of the computation of the eigenvalues of a matrix. Matrices are useful in analyzing complex interrelationships and intersections, mainly because of the way matrix multiplication is defined. Hence matrix methods are useful to biologists and geneticists to analyze complex interrelationships. The first justification for choosing matrices for programming was their utility for the subjects who studied them.

2) It was thought that few of the subjects performance in programmed learning would be contaminated by previous experience. This assumption appeared to be verified in the pretest.

3) Topics in matrix algebra were amenable to a variety of treatments, and within each treatment it appeared feasible to develop the subject content and taxnomy variable sufficiently to collect pertinent data.

Pilot Study -- Matrix Algebra Content[1]

The purpose of this pilot study was to construct programed materials from matrix algebra, and to design and carry out an experiment in which a variety of presentation of program, used as self-instructional materials, could be compared. The theory of matrices was chosen because it is important in its own right. Students should be familiar with these processes that are so important in mathematical applications in many areas including the social sciences. From the viewpoint of the present study the topic appeared to offer sufficient flexibility for the initial exploration of a number of factors important to the present study.

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[1] Portions of these data were used by Richard H. Williams in a doctoral study "An Investigation of the Effects of Method of Presentation and Mode of Introduction on the Learning of Topics From Matrix Algebra." Unpublished Ph. D. Study, Indiana University, August 1964

The programs constructed differ from either the linear or branching formats. There was an attempt to simulate classroom type interaction within a self-instructional format. This ruled out typical programming strategies.[*] The program constructed for this study represents variations on the theme "easy textbook" or "programmed textbook." Materials presented in this program are not put in frames. Correct responses are set in a separate booklet. The answers given are not just one or two word phrases, but complete solutions. The following problem should serve to illustrate:

Problem: Prove that if a matrix A is nilpotent it can have no inverse.

Suggested Solution: Clearly, the zero matrix has no inverse. Assume that A is a non-zero nilpotent matrix and that its inverse is B. This means there exists an integer n such that $A^n = O$ but $A^{n-1} \neq O$. Since $A^{-1} = B$,

$$AB = I.$$

Multiplying through this equation (on the left) by A^{n-1} gives

$$A^nB = A^{n-1}I$$

or $$A^nB = A^{n-1}, \quad \text{But } A^n = O \text{ and so}$$

$$O \cdot B = A^{n-1}$$

or $$A^{n-1} = O.$$

This is a contradiction for A^{n-1} was assumed to be non-zero.

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[*] An attempt was made to conserve principles acquired from programmed learning studies:

(1) Learning is most efficient when the learner has immediate knowledge of the correctness of his response. (A comprehensive survey of studies concerned with "reinforcement", "the law of effect", etc. is given by Hilgard, E. R. Theories of Learning, 1956)

(2) Learning is most efficient when new ideas are presented in a gradual way. Steps should be small and ideas should progress gradually from easy to hard.

(3) Optimal learning occurs when each individual is allowed to progress at his own speed.

(4) New behaviors are best learned when the learner is actively participating in the learning situation.

Krumboltz and Bonswitz compared different ways of presenting the confirming response in a programmed textbook. One of the methods of presenting the confirming response was called the "isolation approach." In this case the response to the stimulus frame was always a single word or a short phrase. This method. was identical to the way in which the reinforcement was presented in a linear program. The second method of presenting the confirming response was really an innovation. The confirming response was presented as a complete thought. It was usually the correct phrase inserted in the appropriate sentence from the stimulus frame and hence was called the "context approach." A third (control) group was given a completely different program. Results of the experiment indicated no difference between the two groups in knowledge of terminology as measured by a criterion test, however, the "context" group performed significantly better than the "isolation" group when the criterion was "ability to apply principles." Solutions given in the present study are even more complete than those used in the "context" method. It is argued that the completeness of these solutions may facilitate the re-learning of basic facts from ordinary algebra as well as the learning of matrix algebra.

The programmed tests constructed for the present study were about eighty pages long and subdivided into three chapters. (See Appendix 5) Chapter one is entitled, "Definition, Equality, Addition, and Subtraction of Matrices"; and chapter three is called "Division of Matrices." Definitions, theorems, and problem sections are labeled in a systematic way with number indices. The third problem section in chapter two, for example, is labeled "Problem Section 2.3," the second theorem in in chapter one is labeled "Theorem 1.2," and "Definition 3.4" is the label for the fourth definition appearing in chapter three. Thus the k$^{\underline{th}}$ theorem in chapter j would be "Theorem j.k." An organization such as the one used for this program makes it easy for the reader to refer back to earlier portions of the program. Although the sequence of topics developed in this program does not utilize frames, the order in which the steps are presented replicate the instructional situation involving a teacher. There was an attempt to follow the media-process instructional matrix. The eight steps were systematically checked. There may appear to be very large steps and perhaps even gaps between steps, however, this may be due more to the inherent difficulty of the subject matter than to the care taken by the programmer in developing the sequence. Matrix multiplication, for example, is a complex process and matrix addition is quite simple. In completing a unit on matrix addition and introducing a unit on matrix multiplication there is certainly going to be one point or another which will make some readers uncomfortable.

The programs developed here was written in simple language and care was taken to achieve a continuity of presentation. Each new topic introduced depends upon earlier topics. In the proof of a theorem the reasons for the steps were carefully labeled. The earlier mentioned system of labeling was useful in the proofs of important results. The following will illustrate this.

Theorem 1.1: Let A and B be two n x n matrices.
Then $A + B = B + A$.

Proof: $[A+B]_{i,j} = [A]_{i,j} + [B]_{i,j}$ (Definition 1.3)

$= [B]_{i,j} + [A]_{i,j}$ (Commutative Law of Addition for real numbers)

$= [B+A]_{i,j}$ (Definition 1.3)

Since the commutative law of addition holds for the general element--that is, the element in row i, column j--it holds for the matrices themselves, for i and j can take on all integral values from 1 to n.

The programs developed in this investigation are generously interspersed with problem sections, some of the problem sections containing a large number of exercises. Because some of the exercises are rather repetitious subjects used in this study were not required to attempt all of the exercises in all of the problem sections. Once the student felt he had mastered a given concept he was free to go on to a different set of exercises. Consider the properties of the unit matrix and the zero matrix under multiplication to illustrate this. Suppose the relevant problem section contains fifteen problems and the concept to be taught is that I is the identity element for matrix multiplication and so behaves very much like the number one in ordinary algebra, and that O has the same multiplicative properties in matrix algebra as the number zero has in ordinary algebra. Some students may need to do all fifteen problems to master thoroughly these analogies; others may see this almost by inspection. Students in the latter group, are encouraged to move on to other topics immediately if they so desire.

Three elements* are common to both linear and branching programs. These three elements are also inherent in the experimental materials described here. It may be true that the means of reinforcement used in this study are not so "immediate", however, it may also be true that with a solution set such as the one used in this investigation the reader is not so likely to "peek" at the correct response before he supplies his own response.

Since clarity of objectives in constructing a program can best be obtained by stating the objectives as a test, the students' scores on a matrix achievement test are an appropriate measure of the degree to which these objectives were actually realized.[23]

PROCEDURE

Subjects. The subjects used in this experiment were students at Indiana University. In addition to the Guilford-Zimmerman Aptitude Survey each "potential" subject was asked to complete Test Q. This test was designed to give a rough measure of the examinee's previous experience with matrices. A copy of Test Q has been inserted in the appendix 5.

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*(1) The student is continuously involved in the learning process. He must make overt responses to the questions which form the program in order to proceed.
(2) The student gains immediate reinforcement; that is the student is constantly kept informed of the correctness of his responses.
(3) Each student can proceed at his own rate of speed. Thus individualized instruction becomes a reality.

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[23] Nicholas A. Fattu, "Evaluation of Automated Instruction," Education, 83: 406-11, March, 1963

Persons who were able to answer any question beyond question one were not considered as suitable subjects. All others were used in the study. Forty-three persons were given Test Q and only one of those persons was able to respond correctly to questions other than question number one. Hence forty-two persons were retained as subjects. Only three of the forty-two subjects were able to answer question number one correctly. Thirty of the forty-two subjects wrote nothing on the test sheet except their name.

Limitations of the study. Since the sample used in this study is clearly not random, one should be cautious in generalizing the findings of this investigation beyond the group used as a sample. The sample was necessarily small because of the problems involved in getting people to participate in the experiment.

The forty-two subjects were next given a matrix aptitude test. A copy of this is given in Appendix K This test was designed to measure aptitude for learning the programmed material. The Aptitude Test contains forty-two items. The fact that there are as many items on the Aptitude Test as there are subjects participating in the experiment is merely a coincidence. There may appear to be only sixteen items on the Aptitude Test, but this is due to the fact that common instructions were used for certain sets of items. Problem number three on the first page of the test is an example. Each of the items was scored either "right" or "wrong" for each subject. The total number of items answered correctly by each person was determined and these scores were rank ordered. A median split was then used to divide the sample into two groups, twenty-one subjects in each group. The group having the higher scores on the Matrix Aptitude Test is called the "High Group".

Some mathematics teachers prefer to introduce a new concept by presenting it in its most general statement (perhaps as a theorem) and then later giving more concrete instances of the concept. Others would rather introduce a new idea with a simple and concrete illustrative example and then move up to the most general formulation of the idea. Probably most mathematics teachers use a combination of both of these approaches. It is rather surprising that no one has attempted to ascertain which of these methods is most effective. The present investigation was designed to deal with this problem. Two versions of the program were developed: the "Inductive Method," and the "Deductive Method." The Inductive version was constructed in such a way that each new concept was introduced through a series of concrete examples. A general statement of the concept then followed. Here it was possible for a subject to discover the underlying concept before he was told just what the concept was. The following examples should illustrate this.

Examples:

$$\text{Let } A = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}, \text{ Then } A^{-1} = \begin{bmatrix} -2 & 1 \\ 3/2 & -1/2 \end{bmatrix}.$$

$$\text{We have both } A \cdot A^{-1} = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \begin{bmatrix} -2 & 1 \\ 3/2 & -1/2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = I$$

$$\text{and } A^{-1} \cdot A = \begin{bmatrix} -2 & 1 \\ 3/2 & -1/2 \end{bmatrix} \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = I.$$

Now let $B = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$. Then $B^{-1} = \begin{bmatrix} 0 & 0 & 1 \\ 1 & -1 & -1 \\ 0 & 1 & 0 \end{bmatrix}$.

Again we have both $B \cdot B^{-1} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 1 \\ 1 & -1 & -1 \\ 0 & 1 & 0 \end{bmatrix}$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = I$$

and $B^{-1} . B = \begin{bmatrix} 0 & 0 & 1 \\ 1 & -1 & -1 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = I.$$

Although these are only specific instances, what might you hypothesize concerning a matrix and its inverse? We formulate this property in more general terms in

Theorem 3.3: If A is any (square) matrix having an inverse A^{-1} and if $A^{-1}, A = I$, then $A \cdot A^{-1}$ also equals I. That is, if $A^{-1} \cdot A = I$, then $A^{-1} A = A \cdot A^{-1} = I$. (This indicates that every matrix commutes with its inverse under multiplication.)

In the Deductive version of the text the student was introduced to a new idea by the most general statement of the concept. The general statement was then illustrated by more concrete examples. The following is a "deductive" presentation of a concept from matrix algebra.

Definition 1.5: Let A and B be matrices of the same size. Then subtraction of B from A is the same as addition of -B to A. That is, A-B is defined as A + (-B).

Example:

$$\text{Let } A = \begin{bmatrix} 3 & 1 & 2 \\ 0 & -1 & 4 \\ 1 & 1 & 1 \end{bmatrix} \text{ and } B = \begin{bmatrix} 0 & 0 & -3 \\ -8 & -2 & 1 \\ 4 & 4 & -4 \end{bmatrix}.$$

$$\text{Then } A - B = \begin{bmatrix} 3 & 1 & 5 \\ 8 & 1 & 3 \\ -3 & -3 & 5 \end{bmatrix}.$$

$$\text{Also, } B - A = \begin{bmatrix} -3 & -1 & -5 \\ -8 & -1 & -3 \\ 3 & 3 & -5 \end{bmatrix}.$$

(Notice that $A - B = -(B - A)$)

Since programmed materials were designed to be self-instructional, students often study the materials without over seeking the aid of a teacher. Such a procedure, even if it is effective, may seem rather inhuman. A good introductory lecture to a programmed text, designed to properly motivate the student and to give a rather comprehensive overview of the materials, might be useful in helping to make the experience with the programmed materials more meaningful and rewarding. The present study was also designed to examine such a possibility. Two modes of introducing the materials were used. One shall be called "Reading" and the other "Listening." The people in the Reading group began the program on page one and worked independently of any aid or instruction throughout the program. The Listening group, however, spent the entire first session listening to a tape recording. The first twenty minutes of the tape was "motivational material." The various applications of matrices to different branches of science, engineering, and business were described. This material was designed to convince the listener that matrices are indeed useful mathematical objects. The remainder of the tape was designed to give the listener a brief overview of the programmed text. Each listener was supplied with paper and pencil and was instructed (by the recording) to write certain things on the paper. This, too, is best illustrated by taking an example from the tape recording.

> Now write down on your paper the matrices I am about to read. These will be two by two matrices. The first row of the first matrix--reading from left to right--is "one . . . two," and the second row is "three . . . four." Next write a "plus" sign to the right of this matrix and then another two by two matrix whose first row is "three . . . four," and whose second row is "zero . . . minus one." To find this sum--to add these two matrices--all we do is add the corresponding elements. Consider, for instance, the number in the upper left-hand corner of each of these matrices. For the first matrix the number is "one" and for the second matrix the number is "three." If we add these we have "one plus three, or four." So the element in the upper left-hand corner of the sum is "four." You may write an "equals" sign to the right of the sum you have on your paper, brackets for a two by two matrix to the right of the "equals" sign, and the number "four" in the upper left-hand corner. The upper right-hand element of the sum of these two matrices is found by adding the numbers in the upper right-hand corners of these matrices; that is "two plus four equals six." So "six" is in the upper right-hand corner of the sum. In a similar way "three plus zero" gives the element in the lower left-hand corner of the sum--and this is "three"--and "four plus minus one or three" is the final element. So now you know how to add matrices. We will always be adding matrices of the same size. We will not even define the addition of two matrices of different sizes.

After the first session the Listening group began work on page one of the program. Throughout the remainder of the experiment all subjects worked independently of any aid or instruction. Every subject in the experiment was supplied with a complete solution set. There was no restriction placed upon the way the solution sets were to be used. Each subject was informed that the solution set might be used for any one of the following three purposes: (1) To check the correctness of a response, (2) To seek an alternative solution, and (3) To seek hints or guidance to aid in the solution of difficult problems. Each subject was also supplied with a legal pad and was instructed to do all of his writing in the pad.

Each subject spent twelve hours on matrix algebra. Each session was one and one-half hours long and there were two such sessions per week, hence the subjects studied the program for four weeks. Intersession periods were approximately equal for all subjects. The comparable time schedules were set up to eliminate any possible effects of "spaced vs. massed" learning and to eliminate any differences in retention from subject to subject due to unequal lapses of time. Each subject kept a notebook of his solutions. Date, starting, and stopping times were indicated for each session.

Experimental design. The design was a randomized groups design. The experiment was a 2 x 2 x 2 factorial experiment, fixed effects model.[1] The three factors have already been described. One of the factors was score on the Aptitude Test and the two levels of this factor were High and Low. The second factor was the method of presentation and the levels were Inductive and Deductive. The third factor was mode of introduction, and the levels within this final factor were Reading and Listening. As stated above, a median split was used to divide the sample into High and Low aptitude groups. The subjects within each of these two groups were then randomly assigned to each of the four possibilities. A "tree" may help to clarify this.

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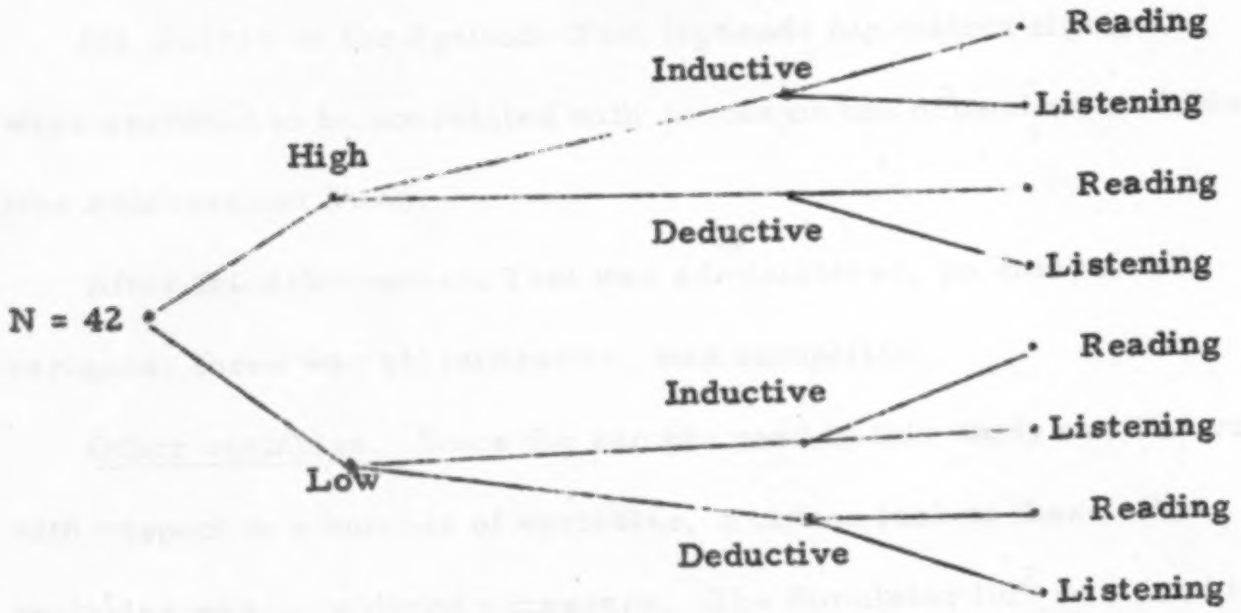
[1] Allen L. Edwards, Experimental Design in Psychological Research, Holt, Rinehart and Winston, Inc., New York, 1960 (rev. ed.).


N = 42
High
Low
Inductive
Deductive
Inductive
Deductive
Reading
Listening
Reading
Listening
Reading
Listening
Reading
Listening

Since N was not a multiple of eight (there were eight treatments), six of the eight cells contained five subjects each and the other two cells each contained six subjects.

After the four weeks of work on the programmed text were completed an achievement test was given to each subject. A copy of the Achievement Test has been placed in the appendix V. The construction of this instrument will be discussed later. Each subject was also asked to complete a questionnaire designed to measure the subject's reaction to the program. This, too, can be seen in the appendix. The subjects were obliged to complete the Questionnaire before taking the Achievement Test for it was quite possible that the experience of taking the Achievement Test would have an effect upon the way the subject responded to the Questionnaire.

Assumptions. (1) It was assumed that subjects would score (essentially) zero if they took the Achievement Test before having studied the program. The subjects' responses to Test O make it clear that this is a reasonable assumption.

(2) Scores on the Aptitude Test (aptitude for matrix algebra) were assumed to be correlated with scores on the dependent variable (the Achievement Test).

After the Achievement Test was administered, an analysis of variance, three way classification, was completed.

Other variables. Since the sample used in this study was heterogeneous with respect to a number of variables, a closer look at these other variables was considered necessary. The Simulator 101[2] was used to tabulate frequencies related to the following eleven variables: (1) Sex--male vs. female; (2) Education--graduate vs. undergraduate; (3) Scores on Aptitude Test--high vs. low; (4) Scores on Achievement Test--high vs. low; (5) Nationality--American vs. foreign; (6) Previous Experience with Programmed Materials--yes vs. no; (7) Number of Problems Attempted obtained from student notebooks median split was used to divide the sample into two groups--high number of problems attempted vs. low number of problems attempted --high vs. low; (8) Method--Inductive vs. Deductive; (9) Mode--Listening vs. Reading; (10) Currently Enrolled in a Mathematics Course--yes vs. no; and (11) Number of Theoretical Problems Attempted (same sort of explanation as variable number seven; these problems were mainly portions of the theorems which the subjects were asked to prove)--high vs. low.

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[2] Research Computing Center and Department of Police Administration, A 709-1401 Program for 101 Simulation, Indiana University, Bloomington, Indiana, 1963.

Aptitude Test. As has already been mentioned, this test consists of forty-two items and each of the items was scored either "right or "wrong." A generous time limit was used and care was taken to keep the items independent of one another.

Validity. The programmed materials were analyzed to determine just what kinds of mathematical skills the reader was assumed to have. Emphasis during analysis was placed upon content validity rather than upon correlation with some outside criterion. An example may help to clarify the analytic procedure. In the development dealing with the concepts of the powers of a matrix and the laws of exponents for matrices it is assumed that the reader already has some understanding of the corresponding concepts from ordinary algebra. It also seemed reasonable to assume that the reader who had not mastered these prerequisite ideas would surely have more difficulty understanding the analogous matrix concepts than the reader who had. Therefore, test items involving exponents are put on the Aptitude Test. In a similar way all of the concepts from ordinary algebra that were utilized in the development of the matrix theory were identified and inserted as test items on the Aptitude Test. Thus the Aptitude Test was designed to measure the degree to which the subject possessed these necessary prerequisite skills.

Biserial correlations were computed for each item to get an estimate of the correlation between each item and the total test score.

Reliability. Let P_i = the proportion of subjects giving a correct response to item i and let $r_{pb(iT)}$ = the point biserial correlation between item i and the total test score. This means we have forty-two r_{pb}'s and forty-two p's. Think of these as the coordinates of points, each point being a test item. The abscissa values of these points are p's and the ordinate values are r_{pb}'s. The forty-two items were subdivided into three sets of items, fourteen items in each set, using content area as a basis for subdivision. Three systems of rectangular coordinates were then drawn and fourteen items (points) were plotted on each system. This is illustrated in Figure 1.

Thus each set of coordinates has fourteen points in the first quadrant, each point representing a test item. The next step was to form seven sets of matched pairs from each set of fourteen points. Here the proximity of the points was used as the matching criterion. The matched pairs from each content area were then randomly assigned to subtests (call the subtests A and B), one member of each pair going to subtest A and the other to subtest B. In this way the forty-two item Aptitude Test was split into two equivalent subtests. These subtests are called matched random subtests.[4] They are matched on three criteria: (1) Difficulty level (p), (2) Internal consistency (r_{pb}), and (3) Content area. Finally, r_{AB} was computed (the ordinary zero order correlation) and substituted into the Spearman-Brown prophecy formula,[5] the result being the reliability of the Aptitude Test.

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[4] Harold Gulliksen, Theory of Mental Tests, John Wiley and Sons, Inc., New York, 1950, pp. 207-210.

[5] Ibid., p. 199.

Achievement Test. This test was based upon the content of the programmed text. Test items on the Achievement Test are questions about matrices whereas the test items on the Aptitude test did not include questions about matrices. Problems on the Achievement Test are very much like the problems in the problem sections of the program. An attempt was made to sample the material in the program uniformly. Test items were designed to measure the degree to which the objectives stated in chapter one were attained. These items were divided into three groups paralleling the taxonomy in Knowledge, Understanding and Application. There were forty-two items on this test, also. A flexible time limit was employed. Care was taken to see that the items were independent of one another. Everything which as been stated about the validity and reliability of the Aptitude Test also applies to the Achievement Test. The same validation procedures and method of estimating reliability were used for this instrument.

The testing of certain hypotheses. The following hypotheses were tested:

(1) H_o : Mean achievement score of High group equals mean achievement score of Low group

(2) H_o : Mean achievement score of Inductive group equals mean achievement score of Deductive group

(3) H_o : Mean achievement score of Listening group equals mean achievement score of Reading group

(4) H_o : The first order interactions are equal to zero

(5) H_o : The second order interaction is equal to zero.

TABLE IV

BISERIAL CORRELATION COEFFICIENTS AND ITEM DIFFICULTY FOR THE APTITUDE TEST

ITEM #	r_b	P
1	.48**	.69
2	.21	.95
3	.23	.95
4	.78**	.50
5	.60**	.33
6	.37**	.86
7	.54**	.74
8	.37*	.83
9	.54**	.67
10	.68**	.60
11	.59**	.62
12	.72**	.60
13	.19	.88
14	.36*	.60
15	.43**	.83
16	.74**	.57
17	.70**	.52
18	.66**	.64
19	.51**	.43
20	.56**	.29
21	.82**	.33
22	.71**	.36
23	.86**	.36
24	.66**	.24
25	.46**	.43
26	.46**	.43
27	.29	.36
28	.49**	.81
29	.57**	.67
30	.53**	.45
31	.54**	.62
32	.86**	.43
33	.69**	.31
34	.35*	.10
35	.73**	.45

* Significant at $p < .05$ level

** Significant at $p < .01$ level

Biserial correlation coefficients were one of the three criteria used to split the instruments into matched random subtests. The other two criteria were content area and difficulty level. Random subtests were formed, the Pearson correlation between them was computed, and the Spearman-Brown prophecy formula was then used. The estimate of reliability was $r'_{xx} = .97$. Experimental studies have shown that different methods of estimating reliability give different results. In general, reliability estimated from parallel forms will tend to be lowest and reliability estimated from odd-even subtests will be highest.[3] The matched random subtest procedure which was used here will not give a gross overestimation of reliability unless the time limit is too stringent or the items are not independent of one another.

The Achievement Test. The same was used with the Achievement Test. Biserial correlation coefficients and the difficulty level indices are reported in Table V. The t-test used here was also a two-tailed test. The reliability estimate for this test was $r'_{xx} = .94$. Hence both of the instruments constructed for this research exhibit satisfactory reliability. Four of the items on the Achievement Test--viz., problems numbered seven, eight, nine, and eighteen may appear to be highly unsatisfactory, however, these items served an important function. These four items were constructed to determine whether or not objectives three, four, five, and six ( ) were attained. It should be clear that the program was highly successful in this respect. Item number one on the Achievement Test is a direct measure of the degree to which ojbective number one was attained. The high p-value (p = .88) for item number one in Table 5 attests to the fact that objective number one was attained. Items three and five are measures of the degree to which objective number two was realized, item number three being the more direct measure of this. Although the degree to which objective number two was attained is not as satisfactory as the others which have been mentioned, the concept of equality of matrices was mastered by a great majority of the subjects. Many items on the Achievement Test pertain to matrix inversion--items twenty-nine through thirty-two, inclusive, and thirty-four through forty-two, inclusive. The p-values for these items can also be seen in Table 5. Subjects seemed to have had varying degrees of success with these items. Although many of these p-values are relatively low, it should not be immediately concluded that objective number seven was unrealistic or that the materials in the program dealing with this topic were poorly written. There is another variable operating here which should be mentioned. Each subject was allowed to spend exactly twelve hours on the program and because of this some of the students never reached chapter three (the chapter which deals with matrix inversion). Hence the low p-values are at least in part a reflection of the time limit. Items numbered twelve and twenty were considered "simple theorems from matrix algebra." The p-values for these items indicate that the subjects in this experiment did not find

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[3] Gulliksen, op. cit., p. 207.

TABLE V

BISERIAL CORRELATION COEFFICIENTS AND ITEM DIFFICULTY FOR THE ACHIEVEMENT TEST

Item #	r_b	P
1	.24	.88
2	.52**	.88
3	.30*	.71
4	.43**	.26
5	.56**	.50
6	.64**	.29
7	.00	1.00
8	.00	1.00
9	.00	1.00
10	.43**	.81
11	.54**	.79
12	.56**	.29
13	.37*	.76
14	.68**	.50
15	.30*	.98
16	.24	.93
17	.42**	.83
18	.00	1.00
19	.53**	.71
20	.52**	.43
21	.58**	.71
22	.40**	.76
23	.30*	.98
24	.47**	.52
25	.63**	.29
26	.82**	.31
27	.65**	.29
28	.49**	.52
29	.67**	.55
30	.55**	.62
31	.70**	.48
32	.72**	.40
33	.43**	.19
34	.56**	.17
35	.68**	.38
36	.47**	.24
37	.72**	.48
38	.60**	.19
39	.63**	.17
40	.45**	.07
41	.61**	.45
42	.76**	.38

* Significant at $p < .05$ level.
** Significant at $p < .01$ level

these items easy. This was not really surprising for most students find it more difficult to deal with abstractions and generalizations than to deal with concrete instances. These low p-values, however, along with certain comments on the questionnaires (which will be discussed later), are indications that the way in which the theoretical materials in the program were presented was not entirely satisfactory.

The analysis of variance. Table VI presents a summary of the analysis used to test the hypotheses. Since there were six subjects in two of the cells and five subjects in all of the other cells, one of the six in each of these two cells was randomly discarded. Bartlett's test for homogeneity of variance resulted in an uncorrected chi-square of 7.088. For seven degrees of freedom this chi-square is not significant. Hence the data offer no significant evidence against the hypothesis that these samples were drawn from populations having equal variances. As can be seen from Table VI factor A was a highly significant factor.

TABLE VI

Analysis of Variance of Scores on the Achievement Test

Source of Variation	SS	df	MS	F
Between Groups(A): High vs Low	1664.1	1	1664.1	52.00*
Between Methods (B): Inductive vs. Deductive	22.5	1	22.5	
Between Modes(C): Listening vs. Reading	4.9	1	4.9	
A X B	0.4	1	0.4	
A X C	10.0	1	10.0	
B X C	40.0	1	40.0	1.17
A X B X C	16.9	1	16.9	
Experimental Error: Within Treatments	1094.8	32	34.2	
Total	2853.6	39		

*Significant at $p < .001$ level

Hence hypothesis number one on page thirty-two was rejected at the $p < .001$ level. This is no surprise since a positive correlation between scores on the Aptitude Test and scores on the Achievement Test was to be expected. As a direct measure of this correlation a Pearson r was also computed. The result was $r = .87$. Other main effects and the interaction terms were conspicuously insignificant. The only other term which it was even necessary to compute was the "methods by modes" interaction. Aptitude for matrix algebra was certainly a potent factor. So potent, perhaps, that the other terms were not given a "fair chance" to show themselves. A randomized block design, the blocking done on aptitude scores, might have been a better test to examine the potency of the other two main effects. The present study was designed to bring out possible interactions of method and mode of presentation with aptitude for matrix algebra as well as to examine the main effects. One might reason that the subjects with lower aptitude scores would prefer to be introduced to a new concept with concrete examples whereas the subjects with higher aptitude scores would profit most by studying the most general statement of a concept initially. That is, one might hypothesize that students scoring lower on the matrix aptitude test would learn more efficiently with the inductive version of the program than with the deductive presentation and that the reverse might be true for the group scoring higher on the Aptitude Test. No such "crossover" effects were found.

Reactions to the program. There was quite a wide range of reaction to the programmed materials. The reactions were generally favorable, however, some dissatisfaction was expressed with regard to two points.

Since a student's reaction to the program is perhaps as important as his degree of mastery of the subject matter in the program, the writer felt that it would be instructive to list some of the students' comments here. All of these comments are verbatim quotations of the responses to the items on the Questionnaire.

> "Well planned. Easy to follow. Good to be able to check steps in solutions rather than having only answers. Completely different; interesting material. Interesting experience; increasing and reviewing my mathematics."

> "Some examples are too confusing. At times during the program, I felt the directions and problems could have been more clear."

> "The materials were for the part clearly written and easy to understand. This program made it possible for each individual to work at his own speed."

> "Explanations and definitions were long and often-times quite complicated. Something simpler would have made learning easier."

> "Education without personal instruction leaves much to be desired. Too many questions left dangling."

> "I enjoyed taking part in the experiment and I think it will be extremely useful if I go further in mathematics."

> "I felt the program was well organized and explained. It followed a logical sequence and was quite easy to understand--in most places. I felt the entire experiment was fun and challenging. It was presented in a very interesting manner."

> "Much more understandable than math textbooks."

> "I have had nothing to compare with this method of teaching. It, however, is a little boring after a while."

> "Very good--comprehensible to pupils with very little background--well planned and organized."

> "For the items taught in the program, I learned them as well as I would have in class. In a class I might have a broader view of application."

"It is logical and self-explanatory. Easy to read and understand."

"Easy to learn from--step by step presentation good--solutions idea excellent."

"I think it is better to have some of the material explained by a teacher rather than reading it. Sometimes I read without knowing what I am reading."

"There were many problems which helped me to be sure I did understand. The answer booklet also was helpful. Most of the explanations were fairly simple and slowly developed. The programmed materials are more slowly and definitely developed than most teacher's lectures or than most textbooks."

"I think the detailed answer book helped tremendously. Sometimes one little point could clear up a lot of doubt and enable you to complete the problem on your own. I've really enjoyed taking part in this experiment and I think I've gained a lot from it. I wish all my classes were like this."

Subjects' comments reveal two major weaknesses in the program: (1) The materials were inadequate in revealing applications of matrices to "real life" situations, and (2) The presentation of the more general results--such as theorems--and the proofs of these results were not satisfactory. Although complaint number two may be partly a reflection of the difficulty of the subject matter, it certainly does appear as though there were a communication problem involved. This is especially true in light of the low p-values in Table V for items numbered twelve and twenty. These two apparent weaknesses should be attended to in the next "edition" of the program.

An analysis of the other variables. The frequencies obtained from the Simulator 101 were used to compute a number of chi-squares. These are listed in Table VII on page . fifty-. eight. All of these were computed

TABLE VII

Chi-Squares Computed from the Frequencies Obtained from the 101 Simulator

Variable	Chi-Square	
Aptitude	21.48*	Achievement
Sex	0.39	Achievement
Education	0.89	Achievement
Nationality	2.04	Achievement
Previous Experience with Programmed Materials	0.00	Achievement
Method of Presentation	0.38	Achievement
Mode of Introduction	0.00	Achievement
Currently Enrolled in a Mathematics Course	2.68	Achievement
Numbers of Problems Attempted	0.86	Achievement
Number of Theoretical Problems Attempted	3.43	Achievement
Sex	0.80	Aptitude
Education	1.74	Aptitude
Nationality	3.22	Aptitude
Currently Enrolled in a Mathematics Course	3.29	Aptitude
Number of Problems Attempted	0.38	Aptitude
Number of Theoretical Problems Attempted	1.53	Aptitude
Sex	0.39	Number of Problems Attempted
Education	0.10	Number of Problems Attempted
Nationality	2.04	Number of Problems Attempted
Previous Experience with Programmed Materials	0.00	Number of Problems Attempted
Currently Enrolled in a Mathematics Course	0.43	Number of Problems Attempted
Sex	0.74	Number of Theoretical Problems Attempted
Education	2.47	Number of Theoretical Problems Attempted
Nationality	0.33	Number of Theoretical Problems Attempted
Previous Experience With Programmed Materials	0.53	Number of Theoretical Problems Attempted
Currently Enrolled in a Mathematics Course	2.69	Number of Theoretical Problems Attempted

* Significant at $p <$ .001 level.

from 2 x 2 contingency tables. In the first chi-square in Table VII, for example, the variables are achievement and aptitude. The corresponding contingency table for this particular chi-square was as follows: the upper left-hand cell contained the number of people in the sample who were high on achievement and high on aptitude; the upper-right hand cell contained the number of subjects who were high on aptitude and low on achievement; the lower-left--high on achievement, low on aptitude; the final cell--low on both achievement and aptitude. Since in all cases of chi-square we have but a single degree of freedom, Yates' correction for continuity was used whenever there was a question as to whether or not the chi-square was significant.[4] Since so many chi-squares were computed, it was deemed necessary to choose a rather stringent α; $\alpha = .01$. Even so, none of the chi-squares were significant at $p < .05$ except the one comparing aptitude scores with achievement scores and that one was significant at the $p < .001$ level. We have seen earlier in this paper that these two variables are not independent of one another. This was revealed in both the analysis of variance and the Pearson product moment correlation coefficient. The chi-squares obtained from the comparison of the frequencies of method of presentation with those of achievement and the frequencies of mode of introduction with those of achievement were $\chi^2 = 0.38$ and $\chi^2 = 0.00$, respectively. This is further verification of the findings reported earlier. The other chi-squares in Table VII reveal that the achievement scores were independent of sex, education, nationality, previous experience with programmed materials, method of presentation, mode of introduction, current enrollment in a mathematics course, number of problems attempted, and number of theoretical problems attempted. Also aptitude scores were independent of sex, education, nationality, current enrollment in a mathematics course, number of problems attempted, and number of theoretical problems attempted. Further, number of problems attempted was independent of sex, education, nationality, previous experience with programmed materials, and current enrollment in a mathematics course. Finally, number of theoretical problems attempted was independent of sex, education, nationality, previous experience with programmed materials, and current enrollment in a mathematics course. Since Achievement Test scores were independent of the other variables, it was deemed feasible to look upon the other "variables" as constants in this experiment. The other variables were also examined in combinations of more than two at a time, but no further information of importance was obtained from these analyses.

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[4] Allen L. Edwards, Statistical Methods for the Behavioral Sciences, Holt, Rinehart and Winston, Inc., New York, 1954, pp. 383-84.

*Study of Teaching FORTRAN Computer Programming

Development of Instruction Materials:

This study was influenced by Roes's (1960) findings which suggested that content that required both a broad perspective and a strong emphasis on synthesis of details into a total process might more readily be implemented by a programmed lecture type of presentation than by conventional linear or branching processes. Treatments were developed in terms of variations on this theme.

A basic analysis of FORTRAN language was made at the outset. This meant starting with the existing structure and analyzing it into its component parts. The process of analyzing the FORTRAN language was simplified by referring to the tables of content and the indexes of published materials in this area. Cross tabulations of basic elements[1] were made to note the frequencies of their interrelationships. Interrelationships among elements were identified and labeled in order of (a) their utility in the language, and (b) their difficulty (the number of prerequisite understandings necessary in order to understand) This identification was done independently by three experienced teachers.

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[1] Roe, Arnold et al "Automated Teaching Methods Using Linear Programs" Report No. 60-105, Automated Learning Research Project, University of California, Department of Engineering, Los Angeles, 1960

* Hall, D. J. "An Exploratory Study of Self-Instructional Text and Lecture Systems of Teaching FORTRAN Computer Programming", Unpublished doctoral thesis, Indiana University, September, 1964. Marilyn Badessa, C. Z. Uthuppuru and David Gray assisted in preparation and writing of materials.

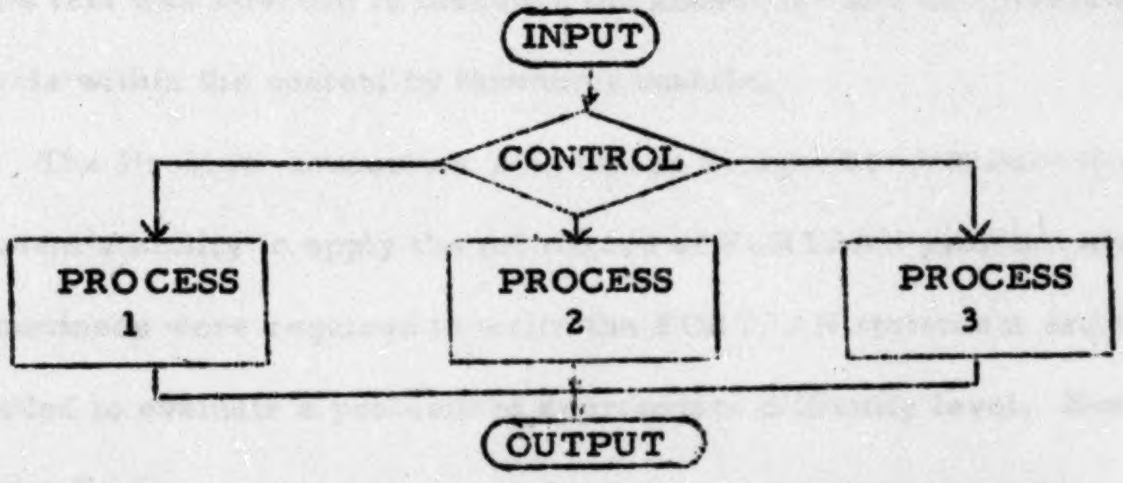


Figure III A Typical Flow Diagram of Problem Evaluation

Instructional Objectives. It was indicated that instructional objectives are a function of the level of performance required of the student upon competion of the instructional sequence. To be regarded as competent within the present context, students were expected to be able to translate a well-defined problem into the sequence of FORTRAN language statements necessary to achieve the desired results; e. g., to evaluate a problem with the aid of reference materials and personal notes made during the instructional sequence.

The depth to which the basic elements of the FORTRAN language were to be covered was restricted because of the limited time available. Four basic tasks in FORTRAN problem evaluation were to be taught in sufficient detail to provide a sound basis for further computer problem evaluation.

Two tests were developed to measure student achievement: a FORTRAN Facts Test and a Problem Evaluation Test. The FORTRAN Facts Test was developed to measure the common factual content of the instructional materials. This test was designed to measure the students' ability to recall specific details plus understanding of principles.

This test was intended to measure the knowledge and comprehension levels within the content by taxonomy matrix.

The Problem Evaluation Tests were designed to measure the student's ability to apply the principles of FORTRAN problem evaluation. Examinees were required to write the FORTRAN statement sequence needed to evaluate a problem of appropriate difficulty level. See Appendix 6.

Preparation of Objectives and Lesson Plans Preparation of the objectives by content (taxonomy by content) matrix was a logical extension of the basic analysis of the FORTRAN publications and of the job analysis of the FORTRAN programmer's work. The basic analysis served as a summary of significant concepts and principles and their network of interrelationships. As such it was useful as a guide to lesson planning.

For example, each task when analyzed into specific actions and their implied sequences of component steps, contained information sufficient for an extended instructional sequence. Long sequences were reduced to shorter sequences to prevent the student from becoming overwhelmed with details and losing sight of the whole process while attending to details.

The FORTRAN instructional content was divided into three logical units in order to provide sufficient material for the time available. Units were designed to build upon the student's present level of understanding until he developed some competence in FORTRAN problem evaluation. Each unit tried to carry out the whole job process at the student's level of understanding achieved from the just completed lesson. Thus, each of the four tasks associated with the job process--input, control, processing, output--was presented three times during the instructional sequences--each time at a more advanced level.

Preparation of Visual Materials and Initial Scripts

Both content and method of presentation were influenced by the need of the student to develop proficiency in conceptualizing problems as a sequence of logical tasks in FORTRAN. Whenever possible, new concepts were introduced and illustrated by their roles in actual problems. See Appendix 6. This strategy was intended to relate new content immediately to a problem-solving content, and at the same time to reinforce the connections between the elements of FORTRAN language and the total job process of problem analysis.

Pencil sketches of the proposed visual presentation, and typescripts of the initial test were prepared for teaching trials. A team of three computer programmers and an audio-visual man worked together during the preparation of these lessons.

Tryout and Revision Initial lessons were tried out by team members and graduate assistants in tutor-like situations. The pencil sketched visuals were presented and the associated audio test with material was read to the subject in the case of the audio mode. The subject read it himself in the case of the visual mode. About 20 subjects were used for a pilot run. Student errors and misunderstandings were noted. After the lesson a follow up discussion of the performance session and the material was held with the student. In this way it was possible to locate and eliminate several gross errors and omissions, as well as to modify the material and presentation toward reducing student errors and increasing student progress.

Tryout of a new sequence appeared to be most useful when conducted immediately before finalizing the content for a pilot tryout of the next instructional sequence. In this way it was felt that not only present problems but possible future ones might be identified and corrected. Course content was modified within a single lesson and/or across several lessons if at any time during tryout and revision it seemed justified.

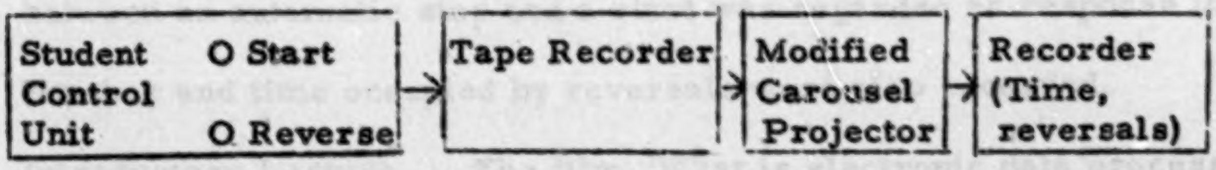
Preparation of Slides, Recorded Lectures, and Workbooks Each lesson was modified in terms of the results of tryout. Visual materials were revised first and then the final script for the lecture was prepared.

Stimulus presentation was made more vivid by using both audio and visual modalities jointly. A variety of devices for directing attention and learning activity could be incorporated--line drawings had the feature to be emphasized in bold outline while the rest is subdued; a sequence of steps involved would be taken up in order--all preceding steps would be kept cumulatively on each succeeding slide, in subdued type, while the present steps were in bold type. An attempt was made to furnish prompts and cues. If materials from several sources had to be referenced they were incorporated into a split slide format. Several methods of cue reduction were tried during the pilot study phase. Active student involvement in thinking was directed by having the instructional device start a demonstration of a problem sequence after a few steps stopping and asking the student to supply the next step. The student did the work in his workbook. When he was done he related the instruction. Upon restarting the device immediately considered this step and discussed why it was correct. On illustrative problems that were solved a student was supposed to be ready at any time to supply a critical step, an argument, or to complete a proof. Realistic problem solving tasks thus provided an opportunity for using information and principles that had been mastered previously.

Assessment of progress during the lesson was coordinated with feedback to the student provided immediately by the next slide presentation.

Workbooks were prepared for eight of the nine lessons used in the experiment. Workbooks were designed to provide a means for active student participation in the lesson, provide supplementary instruction, and supply information needed by the course writers for future revisions. Workbooks were designed in a form analogous to the page segment sequential programmed text of Holland and Skinner (1961). This format provides immediate feedback to the student on each item in a task with a minimum of interprence between items. The feedback on all items of version A of the instructional materials consisted of a correct response hidden from the student by a paper covering. Feedback on selected task items for version B of the programmed materials was presented by the visual and audio presentations of the apparatus.

Apparatus. Apparatus for the programmed lecture consisted of a Carousel Slide Projector controlled by the tape recorder which carried the audio lecture. A student control unit that could override both was placed beside the student on his left. The workbook was on his right. Left-handed people could reverse positions of the workbook and control unit. Functionally the apparatus was as follows:



After the tape recorder and slide projector had been properly prepared, the student was ready to begin work by pressing the start button. Visual and audio portions of the presentation were given by the slide projector and the tape recorder respectively. At the end of a brief instructional sequence the presentation would be set to stop automatically and the student was instructed to work the problem before him in the workbook. After the student wrote his response in the workbook, he would press the "Start" button. This activated the presentation which would begin by considering the correct response and why it was correct. After the explanation it would then stop again. The student could elect to go ahead if he was correct, or if he understood why he was wrong. If not, he could elect to go back and redo the preceding sequence by depressing the reverse button. In fact, he could go back as many sequences as he elected to do so by pressing the reverse button in succession as many times as he wished units to review.

The presentation was set to keep the student alert. In the development of a proof, it would stop and ask him to supply the next step and justify it; a short problem could be posed; a definition or understanding of a principle recalled, etc. If he chose to review, everything was synchromized during reversal, so that upon Restart both the audio and the visual portions were synchromized. A recorder was attached and set to indicate starts and stops, and time between them. Time between an automatic stop and a start was regarded as response latency. Number and time occupied by reversals were also recorded.

Introductory Lecture The film "What is electronic data processing?" was shown to all participants in a group. Viewing was followed by a discussion in which several questions on the ever-expanding role of computers in our society were discussed. The review session was supplemented by a visual presentation of a tour of the Research Computing Center. Discussion shifted to the role of the computer in the University and how one gets to use it. References were made to current computer-oriented research projects. The last part of the introductory meeting was devoted to an overview of the FORTRAN process.

Subjects Participants in this phase of the study were selected from among the High School Science Institute students awarded five-week research assistantships following completion of the Institute. A total of 52 students received research assistantships; 37 were assigned to science departments on the Bloomington Campus and 15 were assigned to research laboratories at the Medical School Campus in Indianapolis.

Of the 37 students on the Bloomington Campus, 12 were randomly assigned to group I which used version A of the programmed lectures, 10 were randomly assigned to group II using version B. The remaining 15 were assigned to group III, whose instruction was based on the IBM FORTRAN Programmed Instruction course supplemented by eight one-hour discussion periods.

The 15 participants at the Medical School used the same materials as group II.

Presentation of instructional sequences. The students in groups I and II were instructed individually with programmed lecture sequences A and B respectively. Three instructional setups, as described in Appendix 6, were provided in the Research Computing Center to present the instruction to the students assigned to groups I and II. The restricted number of instructional setups, plus the demands upon the student's time, made scheduling of instructional sessions difficult.

Students were each assigned a specific schedule with meetings on Monday, Wednesday, and Friday of one week followed by Tuesday and Thursday meetings the next week. This schedule permitted ten sessions during the four week period between July 7 and August 3. Provision was made for make-up sessions on Tuesday and Thursday evenings and Saturday mornings.

The 15 students assigned to group III were issued "FORTRAN--Chapter 1," "FORTRAN--Illustrations," and the "FORTRAN--Problem Booklets" at the beginning of their first meeting. Students were instructed on how to use the programmed texts. After a brief discussion the remainder of the time for the first meeting was used to start the study of Chapter 1. Text materials were collected at the end of the session and held until the next meeting. This was done to keep the text materials away from the other three experimental groups.

The last five sessions were used for open discussion periods. Discussion for each period was limited to questions about material up to a pre-announced portion of the text. This procedure had the effect of pacing the group's progress.

Group IV at the Medical School was instructed using the same instructional materials as Group II. However, portions of the lessons within units were regrouped to permit lengthening each lesson to about one hour and a half. Group IV was required to cover the content in eight sessions; group II had 10 sessions. Make-up sessions were not provided for the Medical School group because of scheduling and the additional travel required.

Testing of Experimental Hypotheses

Administration of FORTRAN Facts Test. The FORTRAN Facts Test (Appendix 6) was administered to obtain a measure of achievement as a function of the student's ability to recall specific factual details about the FORTRAN language. Students were requested not to refer to their notes or reference books while completing this test.

Items on this test were developed from the common content of the three sets of instructional materials used in this project.

Administration of Problem Evaluation Test. The Problem Evaluation Test (Appendix 6) was administered to measure the student's ability to apply the broad principles of FORTRAN problem evaluation in a problem-solving situation. Students were encouraged to use their lecture notes and refer to reference books when necessary.

Analysis of test results. Summary statistics and correlation analysis of all test scores were computed using the Missing Data Correlation Program (G2*UI MISS) on the IBM 709 computer in the Indiana University Research Computing Center.

Based upon the analysis of the correlations and the summary statistics, the covariates were selected for each of the achievement tests. Experimental hypotheses were tested by applying an analysis of covariance model to each set of achievement test results.

Correlations of the aptitude test scores with the two achievement test scores were smaller than anticipated in light of the reported success in trainee selection. An inter-item correlation analysis followed by a factor analysis were computed in an attempt to identify more meaningful covariates to be used in the analysis of covariance for testing the experimental hypotheses. This also permitted exploration of the homogeneity of taxonomic categories.

ANALYSIS OF THE DATA

Sample: A tabular description of the sample used in this study is presented in Table IX

TABLE IX MEANS AND STANDARD DEVIATIONS OF RAW DATA

Variable		Number	Mean	Standard Deviation
PSAT Verbal		27	96.401	4.345
PSAT Mechanical		27	98.000	1.981
Aptitude Test:	Part I	52	17.885	4.305
	Part II	52	26.615	4.049
	Part III	52	13.750	3.174
Total		52	58.346	9.410
FORTRAN Facts		38	38.816	19.185
Problem Evaluation		38	57.947	23.281

The PSAT scores for members of this group are indicative of their ability. A further indication of the sample's general ability is the high IQ scores reported on a variety of IQ tests. These IQ scores ranged from 160 down to 121. IQ scores were not used for statistical analysis because there was no adequate means of converting these scores to a common scale.

Correlation analysis of raw data. Table X presents a correlation matrix of raw data variables. Correlations reported in this matrix were computed on various portions of the total sample depending upon the presence of data for both variables involved in a particular correlation.

TABLE X CORRELATION MATRIX FOR ALL SUBJECTS

PSAT Verbal	1.000							
PSAT Mechanical	.232	1.000						
Aptitude Part I	.240	.464	1.000					
Aptitude Part II	.499	.337	.343	1.000				
Aptitude Part III	.360	.397	.493	.488	1.000			
Aptitude Total	.495	.493	.744	.738	.822	1.000		
FORTRAN Facts	.240	.201	.105	-.003	.331	.222	1.000	
Problem Evaluation	.230	-.094	.205	-.084	.258	.190	.525	1.000

FORTRAN FACTS TESTS ANALYSIS

Results for the FORTRAN Facts Tests are reported in Tables XI through XVII

TABLE XI FORTRAN FACTS TEST DATA

Experimental group	Number of Subjects	Mean score	Standard deviations
I	10	28.700	10.874
II	8	40.625	25.640
III	9	47.333	16.233
IV	11	39.727	20.328
All groups	38	38.816	19.185

TABLE XII ANALYSIS OF VARIANCE OF PERFORMANCE DIFFERENCES ON THE FORTRAN FACTS TEST SCORES

Source	DF	SS	MS	F
Group	3	1,711.553	570.518	1.63
Within group	34	11,906.158	350.181	
Total	37	13,617.711		

The F-ratio is well below the 2.92 required for significance at the five percent level.

The following covariates were considered the next meaningful: (1) Aptitude Test, Part I, (2) Aptitude Test, Part III, (3) Aptitude Test, Parts I and III, and (4) Aptitude Test, Total Score. Analyses of Covariance were computed for all four of these covariates and reported in Tables 9 through 12.

TABLE XIII ADJUSTED MEANS FOR THE FORTRAN FACTS TEST DUE TO THE REGRESSION OF THE COVARIATES

Experimental group	Raw mean	Aptitude Test Covariates			
		Part I	Part III	Parts I & III	Total
I	28.700	29.186	37.149	29.308	29.885
II	40.625	40.715	39.670	39.645	39.902
III	47.333	48.305	48.593	48.505	49.234
IV	39.727	38.424	38.799	38.928	37.620

TABLE XIV ANALYSIS OF COVARIANCE OF PERFORMANCE DIFFERENCES ON THE FORTRAN FACTS TEST SCORE WITH PART I SCORE OF APTITUDE TEST AS THE COVARIATE

Source	DF	SS	MS	F
Group	3	1,760.024	586.675	1.654
Within group	33	11,708.203	354.794	
Total	36	13,468.227		

TABLE XV ANALYSIS OF COVARIANCE OF PERFORMANCE DIFFERENCES ON THE FORTRAN FACTS TEST SCORE WITH PART III SCORE OF APTITUDE TEST AS THE COVARIATE

Source	DF	SS	MS	F
Group	3	1,760.742	586.914	1.869
Within group	33	10,361.924	313.998	
Total	36	12,122.666		

TABLE XVI ANALYSIS OF COVARIANCE OF PERFORMANCE DIFFERENCES ON THE FORTRAN FACTS TEST SCORE WITH PARTS I AND III SCORES OF APTITUDE TEST AS COVARIATES

Source	DF	SS	MS	F
Group	3	1,748.457	582.819	1.800
Within group	32	10,359.895	323.747	
Total	35	12,108.352		

TABLE XVII ANALYSIS OF COVARIANCE OF PERFORMANCE DIFFERENCES ON THE FORTRAN FACTS TEST SCORE WITH TOTAL SCORE OF APTITUDE TEST AS THE COVARIATE

Source	DF	SS	MS	F
Group	3	1,789.227	596.409	1.764
Within group	33	11,158.408	338.134	
Total	36	12,947.635		

The F-ratio of 1.869 in Table XV was the largest obtained. This F-ratio is well below the 2.92 required for significance at the five percent level or the 2.28 required for significance at the ten per cent level.

Summary. Upon first observation of the means reported in Table XI it appeared that there might be a significant difference due to experimental group III. However, the results of the analysis of variance reported in Table XII disproved this supposition. The results of the Analysis of Co-variance reported in Tables XIV through XVII support hypothesis I. This isn't very surprising when one considers the large standard deviations reported in Table XI

PROBLEM EVALUATION TEST ANALYSIS

The same procedures were followed for the Problem Evaluation Test as were performed for the FORTRAN Facts Test in the preceding section. Results of these analyses are reported in Tables 18 through 23.

TABLE XVIII PROBLEM EVALUATION TEST DATA

Experimental	Number of Subjects	Mean	Standard deviations
I	10	59.400	14.010
II	8	68.375	17.598
III	9	45.333	29.232
IV	11	59.364	26.341
All Groups	38	57.947	23.281

TABLE XIX ANALYSIS OF VARIANCE OF PERFORMANCE DIFFERENCES ON THE PROBLEM EVALUATION TEST SCORES

Source	DF	SS	MS	F
Group	3	2,345.072	781.691	1.501
Within group	34	17,708.823	520.848	
Total	37	20,053.895		

TABLE XX ADJUSTED MEANS FOR THE PROBLEM EVALUATION TEST DUE TO THE REGRESSION OF THE COVARIATES

Experimental Group	Raw Mean	Aptitude Test Covariates			
		Part I	Part III	Parts I & III	Total
I	59.400	60.189	59.916	60.269	60.179
II	68.375	68.520	67.618	67.818	67.899
III	45.333	46.909	46.331	47.041	46.583
IV	59.364	57.251	58.628	57.583	57.977

TABLE XXI ANALYSIS OF COVARIANCE OF PERFORMANCE DIFFERENCES ON THE PROBLEM EVALUATION TEST SCORE WITH PART I SCORE OF APTITUDE TEST AS THE COVARIATE

Source	DF	SS	MS	F
Group	3	2,026.050	675.350	1.296
Within groups	33	17,188.605	520.867	
Total	36	19,214.655		

TABLE XXII ANALYSIS OF COVARIANCE OF PERFORMANCE DIFFERENCES ON THE PROBLEM EVALUATION TEST SCORE WITH PART III SCORE OF APTITUDE TEST AS COVARIATES

Source	DF	SS	MS	F
Group	3	1,981.231	660.410	1.302
Within group	32	16,739.077	507.245	
Total	35	18,720.308		

TABLE XXIII. ANALYSIS OF COVARIANCE OF PERFORMANCE DIFFERENCES ON THE PROBLEM EVALUATION TEST SCORE WITH PARTS I AND III SCORES OF APTITUDE TEST AS COVARIATES

Source	DF	SS	MS	F
Group	3	1,874.552	634.851	1.204
Within groups	32	16,605.889	518.934	
Total	35	18,480.441		

TABLE . ANALYSIS OF COVARIANCE OF PERFORMANCE DIFFERENCES ON THE PROBLEM EVALUATION TEST SCORE WITH TOTAL SCORE OF APTITUDE TEST AS THE COVARIATE

Source	DF	SS	MS	F
Group	3	1,943.990	647.997	1.230
Within group	33	17,385.279	526.827	
Total	36	19,329.269		

The F-ratio of 1.501 for the Analysis of Variance reported in Table 19 was the largest obtained. This F-ratio is well below the 2.92 required for significance at the five per cent level or the 2.28 required for significance at the ten per cent level.

Summary. The results of the analysis of variance reported in Table 19 and the results of the analysis of covariance reported in Tables 19 through 22 support hypothesis II on page 3.

Analysis of Aptitude Test Data

These data were analyzed using a modified version of Garry A Flint's program "Missing Data Phi and Tetrachoric Correlation Program for Point Distributions." This program accumulated all of the possible four-way frequency distributions for the 86 original items. The 3,655 frequency tables are not included in the appendix because of their large number.

Tetrachoric Correlations Between Items

Output of Flint's program includes the tetrachoric correlations computed from each of the frequency distributions. Many of these correlations were -1.0. A tetrachoric correlation of one is not uncommon when the sample size is small. The tetrachoric correlation usually tends to give a high estimate of the correlation for small samples. The tetrachoric correlation matrix was not used in the factor analysis for the above reasons.

Factor analysis of item correlations. MESA-1, a factor analysis program written by Clarence Bradford, was selected from the Research Computing Center program library to perform the factor analysis. This program is designed to accept raw data and compute the product moment correlation matrix to be factored. The product moment correlation computed with binary data is identical to the phi correlation computed from the four cell frequency distribution table obtained from the same binary data. Thus, the items on the aptitude test were scored one for a correct response and zero for incorrect or no response.

Item five of Part I and items one and two of Part II were eliminated as variables because all the students in the sample answered these items correctly. The product moment correlations, or in this case the phi correlations, were then computed for the remaining 83 items. The phi correlation matrix appears in Appendix 6. MESA-1 then factored the correlation matrix producing a table of eigenvalues and an unrotated factor matrix of the first 20 eigenvectors. MESA-1 then proceeded to rotate the original factor matrix using the Varimax Rotation criterion. The rotated factor matrix was then printed. (Appendix 6)

The program then computed the regression equation associated with each of the 20 factors. These equations were then used to compute factor scores from the item scores for each of the students in the sample. Three cards were punched for each student containing his scores for each of the 20 factors.

Investigation of factor scores as covariate variables. The 20 new factor scores were combined with the original aptitude test data and evaluation data. A stepwise regression analysis was then run using BIMD 34 to determine the most meaningful combination of variables to use as covariates for each of the evaluation tests.

FORTRAN Facts Test Analysis using factor variables. The first four steps of the Stepwise Regression on the Facts Test scores are given in Appendix V. Factor variables 16 and 21 entered the regression first in that order. Then Part III entered followed by factor variable 5. These four variables were used as covariates in the Analysis of Covariance model reported in Table XXIV.

TABLE XXIV: ANALYSIS OF COVARIANCE OF PERFORMANCE DIFFERENCES ON THE FORTRAN FACTS TEST SCORE WITH FACTOR SCORES 5, 16, and 19; AND APTITUDE TEST SCORES FOR PART III AS THE COVARIATES

Source	DF	SS	MS	F
Group	3	2,025.367	675.122	2.068
Within groups	30	9,794.753	326.492	
Total	33	11,820.120		

The F-ratio is larger than that for Table 15, but it is still not large enough to be significant even at the ten per cent level.

Problem Evaluation Test Analysis using factor variables. The first four steps of the Stepwise Regression on the Problem Evaluation Test scores suggested factor variables 3 and 10 and aptitude scores for Part II and III as covariates. The results of this combination of covariate variables is reported in Table XXV.

TABLE XXV ANALYSIS OF COVARIANCE OF PERFORMANCE DIFFERENCES OF THE PROBLEM EVALUATION TEST SCORE WITH FACTOR SCORES 3 AND 5, AND APTITUDE TEST SCORES FOR PARTS II AND III AS THE COVARIATES

Source	DF	SS	MS	F
Group	3	2,227.908	742.636	2.017
Within groups	30	11,043.781	334.793	
Total	33	13,271.689		

Again there was an increase in the F-ratio but not enough for significance at the ten per cent level.

Summary. The factor variables provided a moderate improvement in the F-ratio. However, the improvement did not warrant the additional work necessary.

Analysis of Other Variables

At the end of the five-week research assistantship period, the participants were brought together for an evaluation of the High School Science Institute and the Research Assistantship Program. During this meeting each student completed the evaluation questionnaire in Appendix V. This questionnaire was designed to serve as a guide to assist in improving the materials and method of presentation.

Responses to the "personal comments" item revealed that many of the participants resented the imposition upon their personal time. These students may have resented being told by the directors of the institute that they were required to participate in this series. This may be one reason that over 15 per cent of the group did not complete the FORTRAN series. It is impossible to determine the effect of this attitude upon their learning and thus upon the results of this research.

The average time required for the nine lessons in the programmed lectures was ten hours. The major complaint of students in the programmed text group was that it required too much time, in excess of 18 hours for most.

ON SIMULATION

"To simulate is to give the appearance or effect of; to have the characteristics of".[1] Actually, simulation is better described by operating a model. When one thinks of such models he sees a small boat being run through a tidal basin or a miniature aircraft in a wind tunnel. In both instances the designer may have found the mathematics too involved or not available, or he may have wanted to verify his mathematical calculations empirically.

In computer simulation[2] one does not have to follow the analytical path of the mathematician. He can tell the machine in general terms how a certain phenomenon takes place, program it to run this activity a few million times under varying circumstances, and then to give a simple summary of what happened.

HOW DOES A COMPUTER SIMULATE?

One may ask how a computer simulates. This is a long story that perhaps can best be told by going through a simulation program. A rough approximation to an answer can be made by asking: How does one use pencil and paper to do whatever he does with them?

Pencil and paper permit one to store and manipulate symbols that represent ideas; they help him with the bookkeeping in a complex process. Paper and pencil can be used to store more than numbers. Ideas may be written on paper and then associated by drawing connecting lines among them. Items may be put on slips of paper and these slips may be sorted and connected as desired. Similarly, a computer memory is well suited both to moving items and making the connections among them.

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[1] Webster's New International Dictionary. Unabridged, 1961

[2] "Simulation-The dynamic implementation of a model representing a physical or mathematical system and its phenomena by computers or other equipment initiating the behavior of the system in order to enable study of the system." W. B. Fritz, "Selected Definitions," Communications of the ACM, 6:152-58, January, 1963. (Dr. Fritz is chairman, ACM Standards Committee Subcommittee on Programming Terminology.)

A useful example is that of the widely known concept-attainment strategy described by Bruner, Goodnow, and Austin (1961). Among others, Reitman (1959) and Baker (1964) discuss simulation of this strategy.[3] Cards bearing representations of objects that differ in certain attributes -number, shape, color, and number of borders--are presented to a subject one at a time. A concept is defined by a set of values of these attributes. Cards carrying symbols of these defined values are called positive instances, e.g., three red objects. A card with three red triangles inside a green border is a positive instance. A card with three green squares inside a pair of blue borders is a negative instance. A card is presented, the subject makes his choice, and then is told whether it is a positive or negative instance.

A focus strategy, used by some subjects, begins with a positive instance, e.g., a card that contains all the values of the concept. The card's values are memorized. If the first positive card is one with three red triangles and two green borders, the concept definition would contain three red triangles and two green borders. Then the definition is only changed when a positive instance which differs from the definition is encountered, say yellow circles and two blue borders. At this point a new definition incorporating features common to the two positive instances is formed, i.e., three objects within two borders.

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[3] See bibliography.

The sequence of actions in following such a focus strategy for concept attainment might be simplified into the following steps:

1. Obtain a positive instance.
2. Memorize the value of each attribute as a tentative hypothesis.
3. Obtain the next instance.
4. If this instance is the same as the hypothesis, examine the next instance. If different, go to the next step.
5. Examine the feedback file indication as to whether the card is an instance of the concept.
6. If indication is "no", examine the next instance (repeat step 3); if "yes" go to the next step.
7. Revise the hypothesis to include values common to the previous hypothesis and the present instance.
8. Are there any instances left? If "no", exit with the revised hypothesis as the concept; if "yes" repeat Step 3.

In contrast to this example, Reitman (1959) and Baker (1964) present more sophisticated strategies for concept attainment. Baker requires display of all cards that are members of the concept and uses a scanning strategy that requires a fairly extensive memory. If cost of feedback information and time are considered as factors, Baker's program is far more efficient. More complex strategies have also been described by Feigenbaum and Feldman (1963), Hunt (1962), and Laughery and Gregg (1962).[4] These more complex strategies, however, require the greater capabilities of a general purpose computer.

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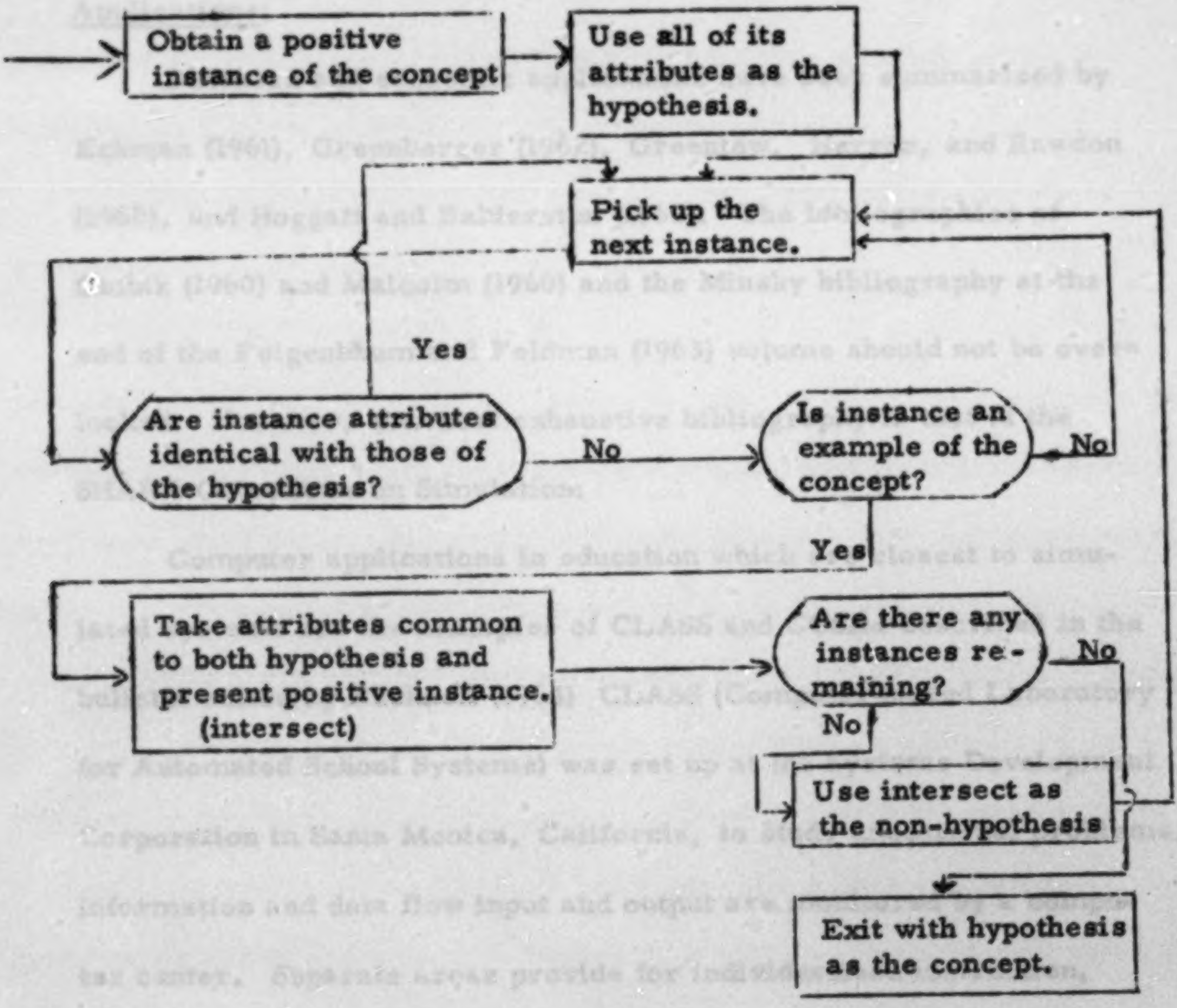
[4] See bibliography.


Obtain a positive instance of the concept
Use all of its attributes as the hypothesis.
Pick up the next instance.
Yes
Are instance attributes identical with those of the hypothesis?
No
Is instance an example of the concept?
No
Yes
Take attributes common to both hypothesis and present positive instance. (intersect)
Are there any instances remaining?
No
No
Use intersect as the non-hypothesis
Exit with hypothesis as the concept.

Applications:

Business and economic applications have been summarized by Eckman (1961), Greenberger (1962), Greenlaw, Herron, and Rawdon (1962), and Hoggatt and Balderston (1963). The bibliographies of Shubik (1960) and Malcolm (1960) and the Minsky bibliography at the end of the Feigenbaum and Feldman (1963) volume should not be overlooked. However, the most exhaustive bibliography is that of the SHARE Committee on Simulation.

Computer applications in education which are closest to simulated systems are the examples of CLASS and COSIM described in the bulletin edited by Bushnell (1964) CLASS (Computer-based Laboratory : for Automated School Systems) was set up at the Systems Development Corporation in Santa Monica, California, to study educational problems, Information and data flow input and output are monitored by a computer center. Separate areas provide for individualized instruction, group instruction, counseling and observation, and administration. This is an example of the "blue-sky" approach--a small, rather expensive installation based upon the prototype of RAND which has been found so useful and productive of innovations for military and industrial application.

Additional work described by the Bushnell (1964) bulletin includes electronic data processing in school administration, automation of scheduling procedures, retrieval of educational information, computer based instructional systems, and systems design and analysis, as well as simulation and modeling. Although the orientation of the bulletin is computer utilization, much of what is said is relevant to simulation.

While computer simulation of systems concerned with fiscal needs, personnel allocation, resources allocation, assembly line balancing, determination of plant location, and determination of bidding policies are commonplace in industry, similar work in educational administration remains largely unpublished.

Yasaki (1963) indicated that the current interest in educational data processing parallels the growth in business data processing and suggests that educators could profit from the experience of industrial managers. Once developed, such procedures could profoundly influence information processing in educational research and instructional processes by providing the basic data needed for simulation. Simulation of cognitive behavior, study of small group interactions, and analysis of social systems offers educators a rare opportunity for unique contributions. Unfortunately, persons without a primary commitment to education have been doing the pioneering research. Before much more progress can be expected, it will be necessary to develop persons competent in simulation whose primary commitment is to the field of education itself.

The significance of simulation for education rests upon the assumption that better educational practice will come from improved understanding. An unprogrammed computer knows nothing and can do nothing. If we are to develop a system which enables the machine to analyze interrelations among a string of symbols, we have to specify that system-both the definitions of the symbols and the interrelations among them. Also, we need to know a great deal about the analysis of that string of symbols. If we understand this fully, the simulation will testify to our understanding by analyzing the string correctly. If we don't, the errors in the simulation will testify to that, too. This kind of research can force us to refine and develop our understanding of what we teach, how we teach it, how our organizational structure actually works, whether we use our resources efficiently to accomplish the objective we desire, etc. In other words, the product would be to make rough notions precise and intuitive knowledge explicit.

One product may be a better grasp of subject matter, such as one gains from writing a first-rate programed text, but with the added dividend that by incorporating the analysis in a simulation program one insures a strict test of its adequacy. If the analysis is at all inadequate, the simulation will reveal it.

The teaching process might be improved by the increased understanding provided by testable models of the process that goes on when we learn about and solve problems. There are psychological models of how we learn to associate words with things, Feigenbaum (1963); of how we comprehend the meaning of sentences, Yngve (1963); and models of how we solve a variety of other problems, Newell, Simon, and Shaw (1961), Feigenbaum and Feldman (1963), Laughery and Gregg (1962).

With such models of the learner available we should be able to begin turning our attention to models of teachers and the teaching process. Here the work of Pool and Abelson (1961), Coleman (1962), and McPhee (1963) should help with the definition of the units and their interactions. Such models, because they specify all of the essential details of the process, should enable us to test ideas about teacher and teaching effectiveness more comprehensively than has ever been possible to date.

Use of computers and computer simulation by individual schools is not fantastic. It may not be too many years before schools will provide teachers with computer simulation assistants. The Carnegie Institute of Technology has computers in use in a limited way as diagnostic and pedagogical devices to correct students" answers to problems and provide them with immediate information about what they have done correctly and incorrectly. As we become more capable of specifiying the structure of what we are teaching, it is quite likely that simulation will provide instructional assistance.

In resource allocation for education, simulation may well provide more refined techniques for measuring fiscal needs and costs. It has the potential for assessing the extent to which schools use rational measures of need in preparing budgets or rational measures of performance for quality control. It is apparent that school traffic flow and problems of space allocation will be dealt with soon. Explicit simulation of other more basic internal operations of the educational system may be a little farther away.

Study of administrative organizational structure could follow almost by direct analogy from related simulations in business and industry. The extent of control achieved over the system, the effects of management patterns, and the effects of resource allocations appear to be similarly tractable.

Studies of public and professional reaction to various practices could be directly simulated following McPhee (1963), while studies of social forces influencing student and teacher behavior could be almost directly simulated by following Coleman's lead.

In other words, there is a great potential for the improvement of educational practice through simulation. Whether this potential materializes depends upon how well the profession responds. The value of the simulation method ultimately depends upon the capability of the individual who is doing the simulation. The strategy requires the applied researcher to learn far

more and to be far more inventive than his predecessors. Whether simulation proves useful to education depends ultimately, then, upon the standards set for such practice by the profession, and upon the support it is able to obtain from the public.

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Educational Organization Simulation - Work at S. D. C.

The System Development Corporation has pursued the application of simulation to an educational problem probably longer than any other group in this country. Emphasis has been recently placed by SDC upon describing school organizations that can accomodate modern instructional media. Any innovation such as programmed learning, is used substantially in a school, has a solid impact on the organization of the whole school program. At the present level of capability the educator has to formulate a sample plan, try it out in a real school and observe the problems as they arise. Solution is then attempted on a sort of first-come-first-served basis. The authors[5] indicated this is the way schools were designed in the past, and would continue to be designed in the future unless new solutions could be found.

Five high schools were selected for study. A systems analysis was made. A computer-simulation vehicle was constructed using first SIMPAC and then JOVIAL computer language for the Philco 2000 computer. "When the simulation vehicle is completed it will be used to simulate the five schools that are being analyzed. The major focus ... will be to use the model as a provisional test of the design recommendations..."[6]

The Present Attempt at Simulation

The present attempt at instructional simulation differs in several respects from that of the System Development group: a) the data and model on which it is based differs, b) the intent differs, c)the end result is different in content and intended use. The SDC School Simulation Vehicle version I was designed for modeling of any school organization configuration. The rules and configuration of the first pilot version represents a hypothetical school operating under the Continuous Progress Plan. It describes dynamically the flow of students through the system. Emphasis is upon describing school organizations that can accomodate modern instructional media.

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[5] Cogswell, J. F., R. L. Egbert, D. G. Marsh and F. Yett "Construction of School Simulation Vehicle." Technical Memorandums, TM-1409, System Development Corporation, Aug. 1963.

Egbert, R. L. and J. F. Cogswell "System Design for a Continuous Progress School, Part I." Technical Memorandums, TM-1493/103/00, Systems Development Corporation, Feb. 1964.

Egbert, R. L. and J. F. Cogswell "System Design for a Continuous Progress School: Surveillance and Detection System." Technical Memorandums, TM-1493/10 4/00 SDC, March 1964.

It was expected that the results could be generalized to other schools. The SDC studies should help in defining roles of various people in schools that use different types of instructional media.

A tool like this is valuable not only for its expected outcomes and recommendations, but also for supplying a valuable conceptual tool for planning effective school systems.

In contrast, our present effort is much more modest. It is not concerned with either school organization or roles of school personnel. It is concerned with instructional media, but more in terms of the curriculum writer and the teacher's point of view than the administrator's.

Our system analysis was concerned with the effects on students of audio-visual media variables (treated as a bivariate relationship and scored on a media x functions analysis), content variables (treated as a bivariate relationship scored on the taxonomy x content analysis) and aptitude variables (originally the attempt was to define them in Guilford's Structure of Intellect terms, but was changed when it became too cumbersome to deal with them in terms of test scores--vocabulary, number facility, etc. --so that either Guilford's SI or the hierarchical model could be used.) In making the system analysis several strategies for expressing trade-off relationships were tried--isolobes, a sorting procedure followed by a

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[6] Cogswell, J. F., R. L. Egbert, D. G. Marsh, and F. A. Yett "New Solutions to Implementing Instructional Media Through Analysis and Simulation of School Organization". Technical Memorandum TM-1809, March, 1964.

statistical summary routine, and factor analysis. The simulation language used was SIMSCRIPT and the program was prepared originally for the IBM 709*. Analysis of selected audio-visual instructional variables was made on topics in the areas of matrix algebra, FORTRAN programming, symbolic logic, and statistics.

The main contributionsof the present study are: (1) to explore relationships among variables dynamically, (2) to indicate some means of establishing trade-off relationships among media, (3) to suggest means of summarizing data on performance of students in relation to learning situation and learner variables, (4) to provoke new studies of indicating an area in need of information, (5) to provide a means of focusing on loci where intensive studies are needed and likely to pay off.

It was recognized that this would be a study that could begin with conventional statistical design and analysis procedures, but that the problems were so diverse that no finite time would be sufficient to provide information for actual practice thru conventional procedures alone. Results could be obtained for only a few selected segments. This is not unlike that of prospecting for an ore body where core sample drillings are taken out at a few selected spots. These cores serve to suggest the nature of the ore deposit, its extent, and depth. From these data decision makers can judge costs relative to benefits and choose whether to exploit or abandon the site. If the choice is to stay an estimate of the extent of effort can be better made.

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*In the midst of the study our University Computing Center changed from IBM 709 to CDC 3600 equipment. The program now in the process of being written for the latter.

SIMSCRIPT[7] Simscript was used at the time because there was nothing better to be had.[8]

Any simulation is told the structure of the facility being modeled, the rules that the system operates, and the requirements or work load to be processed. With this information the computer uses the programmed rules to run the work through the system operations. During the simulation, the computer can be instructed to keep track of how the system performs according to the programmed measures. The simulated system can then be operated with desired variations, decision rules, and configuration facilities. Comparing simulated operation of alternate systems under a variety of conditions sometimes uncovers facts that are overlooked in traditional static analysis.

Any digital simulation consists of a numerical description of the "status" of the simulated system. This status description is modified at various points called "events". A standardized definition form is used for specifying status description in SIMSCRIPT (See Manual, Figure 1, page 4) It automatically provides a main timing routine to keep track of simulated time and the occurrence of events. An "Event Routine" is then written for each kind of event describing how the status is to change.

"Status" of the simulated system is defined in terms of "Entities", "Attributes" of Entities, and "Sets" of Entities. Any type of unit that is to be independently identified in the simulation is called an "Entity".

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[7] Markowitz, H.M., Hausner, B., and Karr, H. W. SIMSCRIPT: A Simulation Programming Language. The RAND Corporation, Research Memorandum, RM-3310-PR, September, 1962.

[8] In the judgment of our people SIMSCRIPT is an improvement over FORTRAN for this purpose. However, they felt something better could be developed, so they worked on development of PØL, Program Oriented Language. A brief description of PØL is given in Appendix IX.

Each type of Entity is described by its particular "Attributes". The Attributes of a test might be factor leadings, correlation, or trade-off relationship weight.

A Status description may contain any number of different types of Entities. There can also be any number of Entities of a particular type. Entities are considered to belong to the same type if their Attribute names are identical; the values of their Attributes may differ. Thus two aptitudes may be of the same type, although they may represent different test score values.

Whether something is considered an Entity or an Attribute of an Entity depends on whether it is to be independently identified in the simulation. If it is desired to keep track of each aptitude, each aptitude must appear in the Status description as an Entity. If there is no need to distinguish among units, they might appear as "Scores on hand", which could be an attribute of some other type of Entity, such as "Test Number."

Interrelationships among individual Entities may be grouped in the Status description into "Sets", for example "Students having X score in Aptitude I". Entities may be members of Sets and also owners of Sets. Thus "Students" are members of a set belonging to "Unit I, Matrices", and own sets such as "test scores". Entities may be added or removed from Sets.

Status is specified by defining each different type of Entity, Attribute, and Set on the SIMSCRIPT Definition Form. The Definition Form is explained in detail in the language documentation.

A separate subprogram is written for each different kind of Event, telling how it changes Status. A particular Event may be caused to occur repeatedly at a desired point. Thus one routine may describe how Status changes each time a particular teaching unit is requested. Another may describe how Status changes every time a student appears at a teaching unit.

Events are kept track of by an Events List.

Operations performed by Event routines, or subroutines, are:

a) Change the Status of an Entity.

b) Cause or cancel a future Event.

c) Carry out a decision rule.

d) Accumulate and analyze results.

To create a record in memory for a new Entity, say a new student record, write a statement such as "CREATE RECORD X". When a student record is to be removed, a statement "DESTROY RECORD X" will do it and make the space available for other "CREATE" statements.

An attribute value is changed arithmetically by a "LET" statement, for example "LET STUDENT RECORD X = RECORD ($X_1 \ldots X_k$) + RCPTS (Record $X_{k+1} \ldots X_j$)"

If a computation were to be done for each item on the list, the statement would be -- "LET RECORD I = RECORD I + RCPTS (Record), FOR EACH ITEM OF LIST."

Here, "RECORD" and "RCPTS" are Attribute of "STUDENT I" and "LIST" is a Set of ITEMS.

Statements such as "FILE ITEM IN LIST" or "REMOVE FIRST ITEM FROM LIST" are available for moving items in and out of Sets.

Items may be accumulated by standard arithmetic and control operations. Thus, statistical values may be found by a "COMPUTE" statement, i.e.,

Compute M, S, P = MEAN, STANDARD DEVIATION, PERCENTILE RANK

OF SCORE (TESTA), FOR EVERY STUDT OF GROUP I

A "Report Generator Layout Form" which specifies "Form Lines" and "Content Lines" permits generation of output routines.

The original program of this study was prepared for the IBM 709. In the midst of activity the University Computing Center changed to CDC 3600 equipment. The revised program will be prepared for the 3600.

SYMBOLIC LOGIC STUDY

Organization Principles Used in Truth Tables Construction and Analysis

Four presentations of truth-table construction and analysis were organized as sets of controlled stimulus conditions from which learning on the first three levels of Bloom's Taxonomy can be predicted and assessed.

Cognitive functioning at the levels of knowledge, comprehension, and application can be measured by test items which meet the criteria given in the Taxonomy, but in most teaching-learning situations the material presented is not organized, with respect to any objective criteria other than the opinions of teachers and textbook writers about what constitutes acceptable arrangements. That is, learning does not take place under controlled conditions.

In order to take maximum advantage of the descriptions provided by the Taxonomy, the learning situation should be closely controlled from the initial stages at the higher cognitive levels. This necessitates ordering the stimulus conditions (learning materials) in accord with the structure of the Taxonomy. Since the levels in the hierarchy are descriptions of respondent behavior (psychological), an interpretation for the logical organization of subject matter (stimulus condition) is required. A detailed explanation of this correspondence is given elsewhere (See Appendix I). It is sufficient here merely to note that within the structure of the Taxonomy, functioning at a given level is a necessary condition for successful performance at the next higher level. When other conditions, such as transfer, aptitude, etc. are met, the conjoined conditions become sufficient for the expected cognitive behavior. In order to minimize the extent to which learning is the product of conditions that cannot be controlled, learning materials have been so organized that successful achievement on one level is both a necessary and sufficient condition for success at the next higher level.

Subject matter for such a closely controlled learning task had to be relatively simple and yet something with which subjects would not be acquainted. The problem was analogous to the learning of nonsense syllables at the lowest level in the Taxonomy, but since three levels are to be represented, a system of internally related atomic units had to be found. This was similar to building a language from nonsense syllables; i. e., defining rules of grammar, etc. Truth-tables seemed to meet all of the necessary requirements.

Therefore, given learning materials based upon the familiar operations of ordinary language yet technical enough to be new to most subjects, the problem was to organize the materials in a manner that would correspond to the structural arrangement of the Taxonomy. As was already pointed out, this necessitated establishing a correspondence between the kinds of responses described in the Taxonomy on the one hand, and the stimuli which elicit these responses, on the other.

Procedure : The procedure for preparing materials for instruction had several distinct phases.

Phase I was concerned with the structure of the subject matter content. This was outlined in detail using a matrix whose column headings were the first three areas of Bloom's Taxonomy. (These three areas were subdivided as Bloom indicated.) Row headings of the matrix were the topics that constituted the subject matter. At the outset these raw headings would be much more general than later. A series of revision cycles were initiated upon completion of the first draft. The subject matter outline was examined in terms of the highest level of the Taxonomy--in this case, application.

One would simply ask: What does the student need to comprehend in order to be able to make this application? Then, what does the student need in terms of knowledge in order to comprehend the material? Experience with the previous studies indicated that starting at the highest level of the Taxonomy and working down was more productive than the reverse process. This is, of course, still a judgmental subjective procedure, but is rendered less so by the delineation of the steps. It permits several people to pool ideas at each stage of the way, rather than only at the end of a completed product.

When consensus was reached among the three people involved the specifications for writing materials were regarded as being complete. The next phase began by evolving the media by processes matrix. Usually the first media was print. The concepts that were to be communicated (concepts were the elements of comprehension from above) were implemented by prior knowledge and followed by examples for application. Each script was examined by means of the eight processes for clues as to a suitable modality for presentation. Scripts were assembled, edited and revised. The next decision was that of mode of presentation.

PRESENTATION I, (Deductive, non-redundant)

Presentation I represents the skeletal structure which is varied but not modified essentially in the other three presentations. The intention here was to define the organization of subject-matter with respect to the Taxonomy as a criterion.

The presentation begins with definitions. These statements represent the level of knowledge. Statements which relate two or more knowledge level statements and which meet the descriptive conditions given in the Taxonomy represent the level of comprehension. In a similar manner, other statements representing the level of application are introduced. The result is a logically organized presentation of material, deductively similar in form to a very rigorous mathematical derivation, but organized with respect to response, or learner, criteria, indicated in the taxonomy. However, the assumption is made that a coherent, non-redundant presentation is both necessary and sufficient for learner understanding. Since understanding is influenced by many variables, it can only be, at best, predicted. Therefore, the function of presentation I is that of establishing the necessary conditions, or the reference frame, in terms of which variation can be made. Presentations II, III, and IV will therefore be of the basic form as I, but these will embody such additions as repetition, the introduction of extraneous material for greater clarity, more exemplification, etc. That is, additions must be made in order to meet the sufficient conditions for predicting success (understanding) at given levels of aptitudes.

PRESENTATION II An understanding of Presentation I would require very high aptitude as measured by such criteria as the deductive sub-test of the Watson-Glaser Critical Thinking appraisal. Therefore, the criteria for Presentation II, III and IV must be greater predicted understanding for persons scoring lower on certain aptitude variables. Thus additions to Presentation I should be comparable to those strategies employed by teachers in comparable circumstances. Such strategies are repetition of the same material, the substitution of synonyms in definitions, more examples, use of analogy, etc. Presentation II is therefore formally the same as I, but with some degree of redundancy added. (Synonyms are employed, similarities are noted, examples are given, etc.)

PRESENTATION III Presentation III is structually the same as II, but with more exemplification. Whereas, additions in presentation II were mainly at the level of knowledge and comprehension, stress in III was at the level of application, (and indirectly at the two lower levels insofar as they are included in application).

Strictly speaking, according to the hierarchisal arrangement of the Taxonomy the level of application involved the classification of propositional functions using truth-tables. That is, truth-tables can be used to determine whether a function such as $(p \supset q).(p \vee q)$ is a tautology, self-contradictory or contingently true. However, when actual arguments are tested, the additional skill of reducing English sentences to symbolic form is introduced. The procedure for doing this is defined ostensively; i.e., arguments are reduced to symbolic form and then represented as a propositional function. This amounts to adding another dimension at the level of application which is not built up systematically from units at the knowledge level. However, the only alternative would be to develop and explain a coding system such as a computer language. Since this is neither possible nor practical the method of ostensive definition will have to suffice. Thus, when arguments are introduced, application is the level at which learning will take place although it must be realized that the two lower levels are more centrally involved than when functions, which are already in symbolic form, are tested.

This same problem is implicit in Presentation II, but in Presentation III care is taken to introduce simple arguments which can be easily put into symbolic form. For example a sentence of the form "$\sim p$ unless q" is equivalent to $(p \supset q)$ but this fact is not obvious after only one or two examples.

PRESENTATION IV As in the other presentations the basic form, on which correspondence with the Taxonomy is dependent, is the same, however, the concepts are presented inductively instead of deductively. The overall structure is, of course, still basically deductive insofar as a concept which is derived from a more primitive idea must not occur before that from which it obtains meaning. The inductive treatment consists in presenting single instances and gradually building up to the principle or generalization which is to be defined, rather than defining the principle and then giving a few examples. This presentation is considerably greater in length, because when the first instance is presented, the learner has no way of knowing the principle of which it is an example. Increased length does not necessarily mean that more time must be spent in learning the material. Logical rigor is still present, but lengthy explanations are imposed on the basic structure to reduce cognitive strain. The result is that points which may be confusing in the briefer deductive arrangements will not cause loss of time. Hence, for learners with middle aptitude the time required to learn the material from Presentation IV should be about the same as for III. On the other hand, presentation IV would probably be inefficient for learners with high aptitude, but the detailed explanations would most likely be indespensible for those with low aptitude.

Purpose of Study:

The purpose of this study was two-fold:

1. To collect data on comparisons of achievement in Symbolic Logic learning under four modes of instruction, for three levels of the Taxonomy of Educational Objectives -- knowledge, comprehension, application.

2. To study the operational model for relating cognitive criteria in the Taxonomy to subject matter structure.

Procedure for the comparison of methods of instruction:

Probably most writers of textbooks and other instructional materials assume that the order which they adopt for presenting the materials is the one that will maximize student learning. Each author probably has his own way of doing the planning for writing. The strategy here was to adopt a systematic plan that could in part be self-correcting. The first step was that of preparing the Taxonomy by Content matrix such as was done in the previous two studies reported here. The intersections or cells served to define the domain and to suggest, in part, the sequence of presentation of materials. (Sequence suggested by the hierarchical nature of the Taxonomy was modified in response to the requirements for the four modes of presentations. Only the first three levels of the Taxonomy were used, because the subject matter allocations at the Analysis and Synthesis levels could not be reliably classified by three independent judges. The average agreement among the judges was r = .70, .68, .63 for the analysis, synthesis and evaluation categories, respectively. Interjudge agreement on the first three areas averaged about .89.)

In order to carry out specifications of the blueprint what seemed to be required was a meaningfully ordered set of instructional materials which would begin with a definition of the terms and terminate with the presentation of interrelated ideas, in such a way, that if the expected learning took place, the expected responses would correspond to the desired cognitive levels. As indicated in the preceding section, the definition of a term such as "proposition" would be at the level of knowledge. A statement which related two or more knowledge statements would be at the level of comprehension. That is, a statement of how "proposition" is related to "propositional variable" would require an understanding of the meaning of "proposition" and "propositional variable". The next level of the Taxonomy, application, is possible when the subject matter is so well understood that what was learned previously could be applied in specific, individual instances. Hence, an application statement in the learning material is merely a special instance of the general relation at the level of comprehension.

Aptitude dimensions were covered by about 20 of the 27 tests indicated in the factor analysis.

The media x process matrix was used as a guide in the preparation of materials. The eight processes decisions were considered in turn in preparing the instructional materials, the achievement examinations and the study guide. The study guide contains at least one question concerning each separate topic. It attempted to slant the approach of the learner in the direction it was desired to test. Also the study guide provided information as to whether or not the learner had to restudy the material before responding to the items. This is not programmed learning but an attempt to structure the materials so as to simulate the tutor situation. Two modalities of presentation were used--print and programmed lecture.

Sample: Subject were volunteers from the Indiana University Teacher Education program who had previously been tested on the aptitude variables. Sixty-seven subjects were selected: 45 were from the regular School of Education group and 22 were from the experimental INSITE (Instructional Systems in Teacher Education) group. Forty seven were women and 20 were men; 66 were included in the study -- one woman was dropped.

Design: A 3x2 random blocks design was used for comparing three of the four modes of instruction (Presentation #1 was dropped because in the pilot study it proved to be too difficult.) The two treatments were print medium, and programmed lecture. Each subject was randomly assigned to a block. Each subject studied independently according to a schedule arranged for his convenience to provide accessibility to the apparatus and working space. The apparatus used for the programmed lecture was the same as that used in the FORTRAN study. Print media presentations are included in Appendix VII. The programmed lecture was as nearly identical as we could make it. It reinforced the print with verbal material.

TABLE XXVI Means and Standard Deviations on Study Guide Scores

			Presentation Sequence			
			#2	#3	#4	Total
Knowledge Scores	Print	x̄	11.91	12.18	12.55	12.21
		s	2.25	3.45	1.92	2.56
	Programed Lecture	x̄	12.27	13.27	13.45	13.00
		s	2.10	1.62	1.86	1.89
Comprehensive Scores	Print	x̄	11.00	11.27	11.83	11.03
		s	3.29	3.15	2.60	2.93
	Programed Lecture	x̄	10.27	12.45	11.36	11.36
		s	2.36	1.97	1.96	2.23
Application Scores	Print	x̄	10.55	11.09	10.09	10.58
		s	2.84	3.81	2.76	3.10
	Programed Lecture	x̄	10.18	10.27	11.18	10.55
		s	1.72	3.15	3.28	2.76

TABLE XXVII Means and Standard Deviation of Post-Test Scores

			Presentation Sequence			
			#2	#3	#4	Total
Knowledge Scores	Print	$\bar{x}$	13.45	14.36	15.09	14.30
		s	2.50	2.38	1.92	2.31
	Programed Lecture	$\bar{x}$	13.64	14.00	14.73	14.12
		s	1.28	1.95	1.85	1.73
Comprehension Scores	Print	$\bar{x}$	10.64	10.82	11.27	10.91
		s	2.87	2.64	2.15	2.50
	Programed Lecture	$\bar{x}$	10.18	11.27	10.27	10.58
		s	2.20	2.76	2.53	2.46
Application Scores	Print	$\bar{x}$	12.27	12.64	13.64	12.85
		s	2.86	3.69	3.32	3.25
	Programed Lecture	$\bar{x}$	13.18	12.27	13.82	13.09
		s	2.27	2.53	2.64	2.49

TABLE XXVIII Means and Standard Deviations of Time in Minutes

			Presentation Sequence			
			#2	#3	#4	Total
Study Guide	Print	$\bar{x}$	181.5	149.5	181.4	170.9
		s	70.2	53.9	62.5	62.8
	Programed Lecture	$\bar{x}$	240.5	189.5	196.8	208.9
		s	80.7	59.0	56.4	68.1
POST-TEST	Print	$\bar{x}$	58.7	55.4	57.3	56.2
		s	19.9	22.1	11.5	20.6
	Programed Lecture	$\bar{x}$	54.1	65.9	51.8	57.3
		s	20.6	14.6	15.7	17.8

TABLE XXIX Analysis of Variance of Post Test Scores - Knowledge Level

	df	Sum of Squares	Mean Squares	F
Between presentations 2, 3, 4	2	10.24	5.12	
Between instruction modes	1	9.60	9.60	
Remainder	62	313.96	50.64	
Total	65	333.80		

TABLE XXX Analysis of Variance of Post Test Scores-Comprehension Level

	df	Sum of Squares	Mean Squares	F
Between presentations 2, 3, 4	2	4.50	2.25	
Between Instruction Modes	1	1.83	1.83	
Remainder	62	390.37	62.96	
Total	65	396.70		

TABLE XXXI Analysis of Variance of Post Test Scores-Application Level

	df	Sum of Squares	Mean Squares	F
Between presentations 2, 3, 4	2	19.80	9.90	
Between Instruction Modes	1	.97	.97	
Remainder	62	519.23	83.75	
Total	65	540.00		

TABLE XXXII Analysis of Variance of Study Guide Scores - Knowledge Level

	df	Sum of Squares	Mean Squares	F
Between presentations 2, 3, 4	2	10.24	5.12	
Between Instruction Modes	1	9.60	9.60	
Remainder	62	313.96	50.64	
Total	65	396.70		

TABLE XXXIII Analysis of Variance of Study Guide Scores-Comprehension L.

	df	Sum of Squares	Mean Squares	F
Between Presentations 2, 3, 4	2	1.83		
Between Instructional Modes	1	4.50		
Remainder	62	390.37	62.96	
Total	65	396.70		

TABLE XXXIV Analysis of Variance of Study Guide Scores-Application Level

	df	Sum of Squares	Mean Squares	F
Between presentations 2, 3, 4	2	1.35		
Between Instructional modes	1	.15		
Remainder	62	548.94	88.54	
Total	65	550.30		

Results can be easily summarized: there are no significant differences between presentations #2 (deductive with some redundancy), #3 (inductive with some redundancy), and #4 (deductive with substantial redundancy). It may be observed in Table XXVII that apparently Knowledge level scores are larger numerically than Comprehension or Application Level scores. It would be false to conclude that performance was actually comparatively better on the Knowledge level because these are different tests. Although their ceilings are the same, the tests were not scaled for comparative difficulty.

The findings of no significant difference in these tables is congruent with the findings of the earlier studies. One should not jump to the conclusion that the mode of presentation or the instructional medium produced no particular effects. Quite the contrary. Participants entered the study with virtually zero scores, and at the end of the treatment the group means are several times the size of the standard deviations. In most instances score gains are between one-half and two-thirds of the test ceiling. Gains from the experience are decidedly significant. The differences between various treatments and presentation modalities are distinctly not significant. The additional sensory modality and extra time in the case of the programmed lecture plus study guide did not produce gain significantly different from the print medium plus study guide.

In other words, given treatments with equal scores on the media X processes variables matrix, the data do not refute the hypothesis that there is no difference due to hardware or using more than one modality. Similarly the inductive versus deductive sequencing of topic development seems to make no difference, if the content X taxonomy variables in the two are kept constant.

Intercorrelation Results

In order to explore the structure of the measured variables used in this study, intercorrelations among 27 of them were computed. These are computed separately for each modality of presentation as well as for the total group. Results are indicated in tables 1 to 4 of Appendix VIII. The intercorrelations were then subjected to a principal components factor analysis using BMD03M. Orthogonal rotations were performed, and the factor loadings are indicated in tables 5-8 of Appendix VIII for all factors having eigenvalues above 1.4. Because of the small number of cases involved in relation to the number of variables, it was recognized that the factors might not be as clearly defined as they might be, and it turned out that they could not be. In order to study the structure of factors further Tables XXXV to XLII were tabulated. These indicate factor leadings above 0.5 for each mode of presentation and each test score. Factor I for presentations 2 and 4 seem to be quite clearly an achievement factor--the kind of achievement, however, is not differentiated. In the total group, Factor I appears to be composed of Listening comprehension, critical thinking and a measure of divergent thinking. This might be designated as perception factor. In group 3, inductive presentation, no factor pattern emerges. The picture is not clear cut. There were only 66 cases involved. Perhaps with 300 to 500 cases, the factor pattern might have been more stable. Either there is no structure, or factor analysis is of no help in identifying the structure in the variables involved. In this case factor analysis could not be used as a process that was helpful in generating hypotheses.

TABLE XXXV Factor Loadings of Factor I

	PRESENTATION			
Test	#2	#3	#4	Total
1	-.85		-.79	
2	-.81		-.85	
3	-.89		-.83	
4	-.72			
5	-.86			
6				-.51
7		.56	-.52	-.72
8				-.72
9				-.58
10				-.77
11				
12				
13			-.51	
14				
15				
16				
17				
18				
19				
20				
21	-.71			
22				
23				
24		.55		
25				
26				
27				

TABLE XXXVI Factor Loadings - Factor II

TEST	PRESENTATION #2	PRESENTATION #3	PRESENTATION #4	Total
1				
2				
3				
4			-.55	
5				
6				
7	-.50			
8				
9				
10	-.73			
11	-.75			
12		.82		-.81
13		.50		
14				
15				
16		.81		-.80
17				
18				-.68
19				
20			-.80	
21				
22	-.87			
23			-.78	
24				
25		-.88		.74
26				
27			-.82	

TABLE XXXVII Factor Loadings - Factor III

TEST	PRESENTATION #2	PRESENTATION #3	PRESENTATION #4	Total
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12	-.78			
13				
14		.80		
15			.78	
16	.73			
17				
18				
19		-.87		
20				-.52
21				
22				
23				-.72
24			.89	
25	-.86			
26	-.59			
27				-.76

TABLE XXXVIII Factor Loadings - Factor IV

TEST	PRESENTATION #2	#3	#4	Total
1				.82
2				.88
3				.82
4				.61
5				.67
6		.63		
7				
8	.56			
9				
10				
11				
12			-.78	
13			-.73	
14	.55			
15				
16				
17	.92		.73	
18				
19	-.62		.64	
20		-.58		
21				
22		.59		
23				
24				
25				
26				
27		-.85		

TABLE XXXIX Factor Loadings - Factor V

TEST	PRESENTATION #2	#3	#4	Total
1				
2				
3				
4				
5				
6	-.65	-.74		
7			.60	
8	-.58		.78	
9	-.89		.55	
10		-.74	.61	
11			.83	
12				
13	-.76	-.63		
14				-.56
15		.65		
16				
17				
18				
19				.81
20				
21				
22				
23				
24				
25			.51	
26				
27				

TABLE XL Factor Loadings - Factor VI

TEST	PRESENTATION #2	PRESENTATION #3	PRESENTATION #4	Total
1		.91		
2		.91		
3		.78		
4			.57	
5				
6		.50		
7				
8		.53		
9				
10				
11				
12				
13				
14				
15				.82
16			-.81	
17				
18				
19				
20				
21				
22		.57	.87	
23				
24	.90			
25				
26				
27	-.58			

TABLE XLI Factor Loadings - Factor VII

TEST	PRESENTATION #2	PRESENTATION #3	PRESENTATION #4	Total
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14	.58			
15	.68			
16				
17		.85		.78
18	.89			
19				
20				
21				
22				
23				
24				
25				
26				.52
27			.82	

TABLE XLII Factor Loadings - Factor VIII

TEST	PRESENTATION #2	#3	#4	Total
1				
2				
3				
4				
5			-.61	
6				
7				
8				
9				
10				
11		-.92		
12				
13				
14			-.67	
15				
16				
17				
18			-.64	
19				
20	-.81			
21				-.81
22				
23		.50		
24				
25			.54	
26	.56			
27				

SUMMARY

This report consists of a series of studies, rather than a single study. All of the studies are directed toward the explorations of interrelationships among media, processes (instructional prerequisites), content and aptitude variables, and achievement. Achievement here was interpreted as defined by Bloom and others in the Taxonomy of Educational Objectives. The intent of the series is to investigate research problems associated with application as the goal. Emphasis was placed on the cognitive domain. Possible interrelationships to either the affective or psycho motor domains were not explored.

The dependent variables, or criteria were the achievement variables: knowledge, comprehension, application, . . . The independent variables include:

a) audio-visual instructional media variables

b) variables related to the instruction-learning process

c) subject matter content variables

d) aptitude variables

Before discussing the variables, it may be well to rationalize why several studies were done. The intent was to focus on problems involved in application of knowledge to a practical teaching situation rather than upon developing a generalization per se. Many writers in the media field have commented on the fragmentary nature of much of the research and its consequent limited range of usefulness. They have said "We need to find out what media can teach best, and how these media can best be employed. We need to give attention to media as parts of systems for teaching and learning. Fragmentary studies have not provided information sufficiently explicit to bridge the gap between research and practice." It was the ambitious goal of the present study to work on a methodology useful for bridging that gap.

OBJECTIVES:

1. To study the structure of the dependent variables cognitive goal achievement; to explore the naming and referents of the Taxonomy.
2. To study the structure of the independent variables:
    a) audio-visual instructional media
    b) instructional-learning process variables
    c) subject matter content variables
    d) aptitude variables.
3. To prepare specifications based on the exploration in "II" and develop instructional sequences based upon these specifications in the areas of matrix algebra, FORTRAN computer programming, symbolic logic and analysis of variance.
4. To prepare achievement examinations congruent with the specifications.
5. To carry out empirical studies of the materials developed in order to collect empirical data for further analysis.
6. To explore trade-off functional relationships among the independent variables.
7. To attempt to develop a model of the system of media instruction that was studied.
8. To attempt to operate the model, or simulate the operation of the system.

PROCEDURE:

Outcomes of a typical experimental study are relevant under the rigorous conditions imposed. In media instructional practice, it is not possible to impose conditions as rigorously controlled as those in an experiment. Experimentalists speak of quasi-experiments when dealing tion is more education, we have stated an intended goal. But is it in terms of student behavior? Perhaps not. It might be a disquised perecriptive statement; i.e., the goal of education should be, etc. However, the difficulty can be easily circumvented by translating the intention into student behavior. The goal for students is not the simple prima facie acceptance of what constitutes the content of a learning experience. It is rather the disposition to reorganize and reconstruct, to analyze, synthesize, and evaluate, and then to reexamine the problem, to consider alternatives and consequences of alternatives and to synthesize new, more primitive, hypotheses which will be superordinate to previous ones. This, then, is a disposition which would be appropriate at any level in the taxonomy. The question is, however, is this a cognitive disposition?[4] Here the argument comes close to being circular; i.e., the disposition is not cognitive because it is not included in the cognitive domain. But would it be possible to include instances of the kind of disposition in question as teacher intended descriptions and therefore to have them count as cognitive goals to be classified? What we are asking for is an example of thinking about 'thinking'. All examples given in Handbook I are cases of thinking about some subject area, but there with conditions approaching practice. Practice involves complex problems, but if media research is to move from experimental comparisons to practice; it is going to have to tackle at least some of these complex problems. In dealing with such problems one enters a domain of the unfamiliar, where strategies have not been clearly worked out; where methods of study and data collection may resemble current research strategies at the outset, but are likely to be followed by other methods that are quite different. It is not a question of showing one approach is better than another. They have entirely different purposes, and both are necessary. An experimenter carefully lays his ground work to test a hypothesis that fits within the framework of a generalization. If the generalization is not refuted, he has one more brick for the structure of his field. Isolated studies properly carried out provide the building blocks necessary for basic knowledge of a field. They must be available to one who would use them for application. But application also involves a systems analysis of how the various parts interrelate. Also it would be desirable to have a mathematical theory of the consequences of various arrangements. This problem has not been solved in the media field. The strategy of the present study was to work out trade off relationships among the independent variablessince mathematical theory was not possible. Given the basic components of the system, and the rules (trade-off relationships) of how the components were interrelated, it was believed possible to describe how the system operates.

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[4] One way to deal with the problem, at this point, is to say that the disposition is only another name for motivation, which is a pre-condition for cognition but which is itself not in the cognitive domain.

Returning to the independent variables, it was found that instructional media variables were usually defined in terms of devices or hardware. This classification provided little help in describing how useful the device was for instruction. By a series of trials it was found that a bivariate or matrix, definition was more descriptive of the actual role. Media variables were defined in terms of five focii of instruction-learning activity that were regarded as pertinent. Later this number was raised to eight. The media by processes matrix was used as a blueprint to direct the construction of instruction materials. These materials were evaluated during the development process against the specifications. Selection of material to include and the slant given during presentation was such as to lead to equivalent scores between different presentations.

Subject matter content variables were first explored in terms of criteria gleaned from Cronbach and McMurray Test Materials in Modern Education and Bruner The Process of Education. But, these variables did not provide the necessary data. The final resolution was a bivariate, or matrix, classification. Dimensions of the Taxonomy were the columns and the detailed outline of subject matter content headings were the rows. The cells referred to specific items of content for the particular cognitive level. Outlines were prepared in four areas -- matrix algebra, FORTRAN computer programming, symbolic logic, and analysis of variance. Each outline was independently reviewed by at least three judges and an attempt was made to reach consensus on points of difference. Most of the difficulties seem to occur in the upper categories of the Taxonomy -- analysis, synthesis and evaluation. It was difficult to separate these from one another and from application. Factor analyses of the individual items of the achievement tests also supported the first three categories, but were ambiguous on the last three.

The aptitude domain was investigated at the beginning by using Guilford's Structure of Intellect model dealing with five operation categories (cognition, memory, divergent production, convergent production, evaluation), six product categories (units, classes, relations, systems, transformations, implications) and four content categories (figural, symbolic, semantic and behavioral). Of the 120 cells in the model, 75 are actually occupied. Guilford has effectively used the Structure of Intellect model to good advantage somewhat like a periodic table in his successful search for new measures of intellect. In evaluating the model for exploring interrelationships in the media instruction field, the incompleteness of the model and the ambiguity in clearly assigning particular scores to particular cells among the 120 available made the task more involved than facilities could handle. The hierarchical model was next explored and also found inadequate. It was finally decided to compromise and use test scores themselves as measures of aptitude dimensions. The following measures were administered: Ship Destination; Otis; Guilford-Zimmerman verbal comprehension, general reasoning, numerical operations, perceptual speed, spatial orientation, spatial visualization, mechanical knowledge; Christensen-Guilford Fluency Tests: word fluency, ideational fluency, associational fluency, expressional fluency; a vocabulary analogies test (locally constructed); SCAT: verbal and quantitative; Thurstone Test of Mental Alertness: quantitative and language; Brown-Carlsen Listening Comprehension; and Watson-Glaser Test of Critical Thinking. These tests plus special aptitude tests (constructed for this project), in the respective subject matter areas, were taken as defining the aptitude domain.

RESULTS:

1. Exploration of the criterion variables of the cognitive domain took several forms -- logical, judgmental, and empirical. The logical exploration is described in Appendix I under "problems of meaning and reference in

Bloom's Taxonomy: Cognitive Domain." Four principles are applied in this examination: 1) correspondence with empirical data, 2) logical development and internal consistency, 3) external consistency with respect to psychological research, and 4) descriptiveness and completeness. In terms of the logical development and internal consistency principle, the Taxonomy should satisfy three rules regulating a logical division 1) there must be only one defining characteristic at each step, 2) the division must be exhaustive, 3) the successive steps of the division must proceed by gradual stages. In terms of the Wilhoyte analysis (Appendix I) the Taxonomy was found far from complete, but it is still probably the most useful categorization that we have in this area.

The judgmental exploration of the Taxonomy was done in terms of a rating scale involving 12 categories -- logical fertility, originality, organizing power, predictive range, complexity, range of phenomena included, number of novel predictions possible, number of new categories suggested, number of new operating rules, predictive accuracy, and probability of leading to new schema. A five point scale was used. Reliabilities of three independent judgments averaged about .72. Again the Taxonomy received about average weights on the various scales.

The empirical study of the Taxonomy was done by factor analyses of the items in the achievement tests that were developed according to the taxonomy x content matrix specifications. Factor analyses of these test items identified varying numbers of factors ranging from about 10 to 20. These factors appeared to cluster about the lower three levels of the taxonomy -- knowledge, comprehension, application. It was not easy to know how analysis, synthesis and evaluation could be interpreted from these results. This may be in part due to limitations within the tests themselves. Although an effort was made to cover the upper levels of the taxonomy, they may not have been as adequately sampled, and hence would have less opportunity to show up in the analyses. At any rate there seemed to be clear evidence for at least three levels that could be used in further exploration.

2. Instructional materials and strategies were defined in terms of the model involving the taxonomy x content matrix and the media x processes matrix. Instruction was designed to simulate the tutor situation. This meant some variation of a print medium plus a workbook arrangement versus programmed lecture plus workbook. A conventional experimental design using analysis of variance was used at this stage.

The argument was as follows: There was no difference between the media x instructional processes because the variables were adjusted on the basis of judgments derived from the scales to be equivalent. There was no difference between the various presentations, within a subject matter area in terms of content x taxonomy matrix variables because these were constructed to be equivalent. Therefore, in practice, one would not expect the null hypotheses to be refuted except in the case of the operation of aptitude variables. The data did not refute the hypotheses.

In the absence of contrary information, it was decided to go ahead using the variables as they were developed for the model describing operation of the media instruction system. (This observation is limited to the domain covered by the sampling.)

In order that the model may be useful for describing interrelationship, it would be ideally desirable to have a mathematical theory of the consequences of various arrangements. Since this was not possible an attempt to develop a process description was initiated. Trade off relationships among various measures were explored in a variety of ways. Regular multivariate regression and analysis of variance provide answers on a global basis, but are not specific enough to deal with individual combinations. Least squares, curve fitting procedures,were tried and found cumbersome. The problem was that of relating combinations of three dimensions on a two dimensional graph. In each instance the dependent variable was a particular kind of achievement -- knowledge, comprehension, or application -- within a specific domain of subject matter. The method of isolobes was tried at length. This technique is used in pharmacology to explore joint relationships between two drugs in producing an effect. The number of variables is reduced to two by choosing a particular specified effect. Varying amounts of the two variables which jointly produce the specified effect are determined. The plot, or isolobe, of these amounts indicates the combinations required for the equivalent effect. Isolobes are described in Appendix III. Even with a simple model, say, twenty divisions of content, five of instruction and five of aptitude, 1500 isolobes would be required to map out the domain. The number becomes astronomical for the present model.

In order to simplify matters a more pedestrian but more tractable procedure was developed. (Described in Appendix IV.) This procedure is essentially a versatile program controlled sorter using magnetic tape or deck storage of STEN scores.

The process is essentially to sort on a variable "A", an independent variable. Then, singly check variables "B.....J" for directionality. (Directionality implies a sequence of monotonically increasing or decreasing values. If the range is not monotonic but can be broken down into sections, at least half a column in length, that are, do so. Label the directionality and the range over which it holds. Hold only uni-directional subsections within a variable.) Note all unidirectional columns individually and plus reduce (Iverson) all combinations. Establish step size, obtain print out. Use BMD programs to summarize the output as desired.

In all this it is evident that the output is pertinent only to the population represented by the original data. Within this population, however, it is possible to obtain an output for virtually any measured variable.

The last process is that of operating the model to generate results. This involves simulation using SIMSCRIPT for the original explorations.

In constructing a model of an operating school system one can observe and summarize the operation; the parts involved and the rules by which the parts interact are visible or easily identified. Inputs, processes, and output are reasonably clear cut. Given a systems analysis of such systems one can proceed to simulate the system operation as the System Development Corporation has done.

Rules of school operation are numerous but definite. Classes meet in certain specified places at specified times. Courses have definite names, definite prerequistites. A model of school operation can be based on fairly objective data.

A model of media instruction -- how do certain variables -- media, processes, content and aptitude variables interact to produce certain kinds of achievement.

Isolated studies comparing one medium of instruction with another do not face the problem of interactions. Outcomes of such study are relevant under condition "other things being equal". But in instruction other things do not remain equal.

The paradigmused was designed for the complex presentation of the information content of a series of arrays, either simply to exhibit the interrelationships that obtain between the results of various parsings of the elements of the arrays, or to provide a predictive base for the interpolations of inter-and intra-array completions. Original or start input to the system is the values of the categories of an array which defines the word "aptitude".

This is Array I (App.A) Array I is defined recursively thus: rows are the scores attained (in some set integer) on a series of n tests. Columns are the skills exhibited (as operationally defined which are aspects of aptitude verbal skills, mathematical skills, ...). Each intersection of this array defines a particular aptitude; sets of intersections will define particular aptitudes. Only such intersections and sets of intersections define aptitudes.

Aptitudes so defined serve as start inputs to the system. For every aptitude so defined, exemplifications of Array II and Array III will be constructed.

Array II is defined thus: Rows are features of instruction; "Processes" in the SIMSCRIPT terminology (e.g., presenting stimulus, directing attention and learning activity, providing a model of expected performance,...). Columns are instructional media, again aspects of Processes (e.g. printed media, teaching machines, motion pictures,...) This array is not binarily defined over its elements. A three point scale (0, 1, 2) was used to define the element values.

Exogenous events are displayed in Array III. It is defined as follows: rows are subject matter aspects, arranged in ascending order of difficulty (see trade off relationships). Columns are achievement variables, hierarchically arranged (knowledge, comprehension, application).

For display purposes, Arrays II and III are, for each element in Array I, logicall multiplied to obtain an Access Array. The Access Array is a binary array that allows access of the events to the objects for interaction.

For predictive purposes, an incomplete access array is built, and interpolations to fill it out are made.

In terms of the data and the model available, it is possible to operate. The fact that results will fit the data on which they are based merely reflects the redundency inherent in such a system initially. It will be far more useful when predictor made for independent samples can be verified by independent empirical work.

CONCLUSIONS AND IMPLICATIONS

It was possible to make a systems analysis of a hypothetical media instructional system, to develop a model, and to generate results to conform to empirical findings. The value of the approach is not yet known, but it probably will depend on its generalizability to similar circumstances.

The most significant implication is that it is potentially possible to carry out studies that appear to bridge the gap between research and practice in the media field. The methodology is complex and much of it remains to be explored before it can be of operational use. When time for operational use comes, the effort will require efforts that are many orders of magnitude larger than the present.

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APPENDIX I	Problems of Meaning and Reference in Bloom's Taxonomy: Cognitive Domain by R. L. Wilhoyte
APPENDIX II	Scale for Appraising a Model
APPENDIX III	Exploration of Interactions Among Instructional, Content and Aptitude Variables
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APPENDIX V	Matrix Instruction Materials
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